ESTCP
Cost and Performance Report

(ER-201168)

Large-Scale Demonstration of Perchlorate Removal Using Weak Base Anion Resin at Well No. 3 in Rialto, California

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ESTCP

ENVIRONMENTAL SECURITY
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COST & PERFORMANCE REPORT
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ACRONYMS AND ABBREVIATIONS

AF	Acre feet
ARA	Applied Research Associates, Inc.
AWWA	American Water Works Association
Bac-T	best available control technology
bgs	below ground surface
BV	bed volume
CDPH	California Department of Public Health
COTS	commercial off-the-shelf
DAQ	Data Acquisition System
DLR	detection limit for reporting
DoD	Department of Defense
ESTCP	Environmental Security Technology Certification Program
ft^3	cubic feet
GAC	granulated activated carbon
gpd	gallons per day
gpm	gallons per minute
IC-MS/MS	Ion Chromatography-Mass Spectrometry/Mass Spectrometry
IEBL	Inland Empire Brine Line
LC	Liquid Chromatography
LSI	Langelier Saturation Index
µg/L	micrograms per liter
meq	milliequivalents
meq/L	milliequivalents per liter
MVSL	Mid-Valley Sanitary Landfill
NDBA	N-Nitrosodi-n-butylamine
NDEA	N-Nitrosodiethylamine
NDMA	N-Nitrosodimethylamine
NDPA	N-Nitrosodi-n-propylamine
ng/L	nanogram/liter
NMEA	N-Nitrosomethylethylamine
NMOR	N-Nitrosomorpholine
NPIP	N-Nitrosopiperidine
NPYR	N-Nitrosopyrrolidine
O&M	operation and maintenance

ACRONYMS AND ABBREVIATIONS (continued)

O/I	operator interface
PCB	polychlorinated biphenyl
PLC	programmable logic controller
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
psig	pounds per square inch, gauge
RASP	Rialto Ammunition Storage Point
RfD	reference dose
RWQCB	Regional Water Quality Control Board
SBA	strong base anion
SBVMWD	San Bernardino Valley Municipal Water District
TDS	total dissolved solids
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
UV	ultraviolet
VOC	volatile organic carbon
WBA IX	weak base anion resin ion exchange

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EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION

The objective of this demonstration was to test and validate weak base anion resin ion exchange (WBA IX) technology using established performance objectives in order to obtain permitting and certification from the California Department of Public Health (CDPH) as an approved perchlorate treatment technology. This 1000 gallon per minute system was constructed by Applied Research Associates, Inc. (ARA) to treat groundwater at the Rialto No. 3 well site in the Rialto-Colton, CA area under Environmental Security Technology Certification Program (ESTCP) Project No. ER-200312, "Perchlorate Removal, Destruction, and Field Monitoring Demonstration." Because perchlorate concentrations at Rialto No. 3 are elevated, this site is considered to be an extremely impaired source as defined by the CDPH 97-005 Policy Memorandum. ARA worked with water utility and regional CDPH representatives to obtain all of the necessary permits to conduct the test and demonstrate performance. The quantitative performance objectives are: meeting perchlorate regulatory standards; demonstrating posttreatment capability; minimizing process waste, demonstrating spent regenerant treatment; minimizing perchlorate bleed from regenerated vessels; demonstrating treatment flow rates; validating operating costs and future system scalability. Additionally, qualitative performance objectives included demonstrating the ability to model resin treatment capacity for drinking water applications and demonstrating effective system control during operation.

TECHNOLOGY DESCRIPTION

The WBA IX process developed by ARA and Purolite is comprised of three unit operations: 1) pretreatment (pH and alkalinity reduction), 2) ion exchange with two packed-bed vessels configured in series (multi-barrier perchlorate removal), and 3) posttreatment (restoration of pH and alkalinity).

Pretreatment prevents neutralization of WBA resin functional groups during ion exchange. Sulfuric acid is metered into the contaminated source water reducing the pH to levels below the pKa of the WBA resin (i.e., conditions at which 50% of the functional groups are protonated). During pH reduction, alkalinity present in groundwater is converted to carbonic acid. Carbonic acid in equilibrium with dissolved carbon dioxide (CO_2), which remains in solution at operating pressures. Excess dissolved CO_2 is removed to reduce posttreatment costs using Liqui-Cell membranes designed for degassing liquids. WBA IX treatment is conducted in two, packed-bed ion exchange vessels configured in series.

After ion exchange treatment, the posttreatment system restores alkalinity and pH of the treated water. Dilute sodium carbonate (soda ash) solution is metered into the treated water to raise pH and alkalinity. The alkalinity of the final product water is controlled by the amount of dissolved CO_2 that remains after pretreatment. The pH and alkalinity are controlled to achieve product water that is neither scaling nor corrosive. This is determined by calculating the Langelier Saturation Index (LSI) for treated water samples.

After perchlorate breaks through the lead WBA vessel, the vessels are reconfigured so that the spent vessel (lead) is taken offline while the second vessel remains online. This enables treatment to continue while the spent vessel is regenerated. Regeneration is accomplished by

increasing the pH of the spent resin to neutralize WBA resin functional groups. Water is circulated through the resin bed for a fixed time period. Sufficient caustic (sodium hydroxide [NaOH]) is added to the water to neutralize the WBA resin functional groups and achieve a pH of 12.0. The resin is rinsed using perchlorate-free water to remove residual perchlorate. Wastewater produced during regeneration is treated to remove perchlorate. This is performed using a small volume of strong base anion (SBA) scavenger resin. After the scavenger process, the perchlorate-free regenerating solution is discharged and the spent scavenger resin incinerated.

After rinsing, the WBA resin is restored to the ionized or protonated form by decreasing the pH of the resin. During protonation, water is circulated through the resin bed for a fixed time period. Sufficient acid is added to protonate the ion exchange sites and achieve a pH equal to or less than 4.0. After protonation, the resin is rinsed again and returned to service as the lag vessel. The spent protonating solution may be recovered, reused, or neutralized and discharged.

DEMONSTRATION RESULTS

The total value of the subcontract to design, install, and build the Rialto 3 demonstration system was $1.958M. Design and equipment costs accounted for $1.492M with installation costs of $0.466M. Observed costs for the demonstration were higher than anticipated due to fluctuating chemical costs, shortened operational periods, and intermittent operational difficulties. The normalized treatment cost for the demonstration system was $229 per acre-foot water treated.

During the Rialto 3 demonstration, a total of 14,950 bed volumes (BV) (39.15MG) of groundwater was treated over four test periods. The perchlorate concentration of all treated water samples was below the detection limit for reporting (DLR) of 4.0 parts per billion (ppb). During start up, n-nitrosodiethylamine (NDEA) and n-nitrosopiperidine (NPIP) were detected at < 5 BV of water treated, but did not appear after this point. All testing was performed at flow rate of 800 gallons per minute (gpm) (2.29 gpm/cu ft), which was the highest possible flow rate due to equipment and pressure limitations. The first and second test periods were designed to be short cycle tests (1,339 BV and 2,261 BV) where the lead vessel was regenerated after only seven days online and well before perchlorate breakthrough. These tests were designed to improve resin performance by executing more regenerations per vessel to condition the virgin resin. The third test period was designed to operate the system to approximately 50% of resin capacity (4,081 BV), while the fourth test period was designed to operate the system to perchlorate breakthrough. Test period four treated 7,269 BV, but perchlorate breakthrough was not achieved due to operational delays and budgetary constraints. Based on previous ESTCP field demonstrations and models using Rialto No. 3 groundwater characteristics, the lead vessel will treat ≥ 9000 BV's of water before significant perchlorate breakthrough is observed.

Resin was regenerated at the end of the first three test periods. No detectable perchlorate bleed was observed when the regenerated vessel was placed back online as the lag vessel. The spent regenerant volume was limited to 0.07% of the total water treated during testing, which resulted in concentrating the perchlorate to over 35,000 ppb. The SBA scavenger process effectively lowered perchlorate in the spent regenerant to non-detectable levels (< 2.5 ppb).

TECHNOLOGY IMPLEMENTATION

Implementation of this technology is straightforward. Commercial, large-scale, ion exchange equipment for WBA resin technology is commonplace. The pretreatment section of the system consists of pH control unit operations with two-stage static mixing, which is straight forward to design and engineer. Reducing the alkalinity/stripping of CO_2 from the groundwater feed can be accomplished using membrane treatment systems or stripping towers. Both methods are straightforward and are commercially available. The posttreatment system used to restore alkalinity and pH of the treated groundwater consists of a package soda ash delivery system combined with static mixers; both are commercially available. Treatment of residuals by the SBA scavenger ion exchange process is a proven technology.

Parameters that directly affect implementation of the WBA IX technology are groundwater alkalinity, perchlorate groundwater concentration, and treated water alkalinity. The amount of acid required to achieve operating pH is directly proportional to feed water alkalinity. Perchlorate concentration directly affects the amount of scavenger resin required, which can also increase cost. The amount of acid used in pretreatment and the desired alkalinity of the treated water affects soda ash requirements for neutralization, which, in turn, affects neutralization cost. The cost of each of these drivers is affected by fluctuating market prices.

Perchlorate concentration below 1 ppm has little effect on treatment capacity and resin regeneration costs. As a result, the WBA IX process becomes more economical than direct SBA IX as perchlorate concentration increases.

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1.0 INTRODUCTION

1.1 BACKGROUND

The Department of Defense (DoD) has used perchlorate (ClO_4^-) as an oxidizer in ordnance items and rocket motors since the 1940s. This very water soluble and environmentally persistent compound now contaminates drinking water for tens of millions of people in the United States. The cost for DoD to achieve compliance with this drinking water limit could be billions of dollars. The current approach is treatment by ion exchange for drinking water applications. Existing ion exchange technologies used today include regenerable and single-use processes. Regenerable ion exchange processes use salt as the regenerating agent, such as the Calgon ISEP® process and other, more conventional, lead-lag processes. These non-selective regenerable systems require frequent regeneration and generate large volumes of salt brine containing high concentrations of nitrate, sulfate, and perchlorate. This waste stream is becoming more difficult to dispose and the operation and maintenance (O&M) cost from frequent regenerations is high. Single-use ion exchange processes use strong base anion (SBA) resins. After perchlorate loading capacity is reached, the single-use resins must be removed from the ion exchange vessels and incinerated resulting in high disposal and replacement costs.

Applied Research Associates, Inc., (ARA) was selected by the Environmental Security Technology Certification Program (ESTCP) to evaluate and demonstrate a regenerable ion exchange process for removing perchlorate from groundwater. The regenerable process that ARA co-developed with The Purolite Company uses perchlorate-selective, weak-base-anion (WBA) resin. This process has the potential to significantly reduce O&M costs and reduce process waste compared to existing single-use and brine regenerable ion exchange processes.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objective of this demonstration was to test and validate weak base anion resin ion exchange (WBA IX) technology using established performance objectives to obtain permitting and certification from the California Department of Public Health (CDPH) as an approved perchlorate treatment technology. This 1000 gallon per minute system was constructed by ARA to treat groundwater at the Rialto No. 3 well site in the Rialto-Colton, CA, area under ESTCP Project No. ER-0312, "Perchlorate Removal, Destruction, and Field Monitoring Demonstration." Because groundwater perchlorate concentrations at Rialto No. 3 are elevated, this site is considered to be an extremely impaired source as defined by the CDPH 97-005 Policy Memorandum. An anticipated outcome of this demonstration is obtaining data that can be used to modify or revise the current Rialto No. 3 drinking water permit to include WBA IX as a primary treatment technology onsite. To accomplish this, ARA worked with water utility and regional CDPH representatives to obtain all of the necessary onsite permits to conduct the demonstration and determine performance objectives. The quantitative performance objectives are: meeting perchlorate regulatory standards; demonstrating posttreatment capability; minimizing process waste, demonstrating spent regenerant treatment; minimizing perchlorate bleed from regenerated vessels; demonstrating treatment flow rates; validating operating costs; and future system scalability. Additionally, qualitative performance objectives were modeling resin treatment capacity for drinking water applications and whether effective system control was established during operations.

1.3 REGULATORY DRIVERS

Perchlorate is water soluble and persistent in the environment. This is of concern to human health because perchlorate has been shown to inhibit the uptake of iodide by the thyroid gland, potentially impacting thyroid hormone production. On January 26, 2006, the U.S. Environmental Protection Agency (USEPA) adopted a reference dose (RfD) for perchlorate of 0.0007 mg/kg-day.[1] This RfD equates to a Drinking Water Equivalent Level of 24.5 micrograms per liter (or 24.5 parts per billion [ppb]). On January 8, 2009, the USEPA updated the Interim Drinking Water Health Advisory for exposure to perchlorate from 24.5 µg/L (or ppb) in drinking water to 15 ppb. This adjustment was made to account for perchlorate exposure from food in addition to drinking water. Following USEPA's lead, on April 22, 2009, the Office of the Under Secretary of Defense reduced the preliminary remediation goal from 24 ppb to 15 ppb or the State regulatory goal, whichever is least. In California, the drinking water public health goal for perchlorate is 6 ppb.

The anticipated outcome of this demonstration is obtaining a modified or revised drinking water permit that includes WBA resin ion exchange as a treatment process for drinking water treatment applications. To accomplish this, ARA worked closely with water utility and regional CDPH representatives to develop a sampling and analysis plan that provided the data necessary to obtain permit modification. Acquiring the permit modification by the regional CDPH officials will facilitate permit modification in the future for other water utilities in this region (or in other regions) and facilitate technology implementation.

[1] USEPA. Assessment Guidance for Perchlorate Memorandum dated January 26, 2006 http://epa.gov/newsroom/perchlorate.pdf

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

2.1.1 WBA Resin Chemistry

ARA and Purolite developed the regenerable ion exchange process to take advantage of the pH-dependent nature of WBA resins. At low pH, WBA functional groups on the resin have a positive charge (i.e., R-NH3+), allowing anion exchange to occur. However, at high pH, the functional groups lose a proton and become uncharged (i.e., R-NH2) and no longer attract the counter anion. It is this loss of a proton that enables the efficient and complete regeneration of the functional groups. The pH dependent nature of WBA resins enables efficient regeneration, minimizing the amount of regeneration chemicals consumed, which results in an economical process. Equations representing the pH-dependent chemistry of WBA functional groups are shown in Figure 1.

WBA resin in free-base form ($R\text{-}NH_2$) is ionized ($R\text{-}NH_3^+$) by protonating with acid (H^+):

$$R\text{-}NH_2 + H^+ \rightarrow R\text{-}NH_3^+$$

Protonated resin removes anions (A^-) from aqueous streams:

$$R\text{-}NH_3^+ + A^- \rightarrow R\text{-}NH_3\text{-}A$$

Spent resin ($R\text{-}NH_3\text{-}A$) is regenerated by neutralizing with caustic (NaOH), which liberates anions and returns resin to the free-base form:

$$R\text{-}NH_3\text{-}A + Na^+OH^- \rightarrow R\text{-}NH_2 + HOH + Na^+A^-$$

Figure 1. Weak base anion resin chemistry.

2.1.2 WBA Ion Exchange Process

The WBA ion exchange process has two primary modes: operation and regeneration. During operation, perchlorate is removed from the contaminated water. Once the resin has reached its exchange capacity for perchlorate, it is considered "spent" and the resin must be regenerated before it can be returned to the operational mode. These modes are described below.

2.1.2.1 <u>WBA Ion Exchange Operation</u>

Because of the pH dependent nature of WBA resins, pH must be controlled during the ion exchange treatment process. The general ion exchange process developed by ARA and Purolite is comprised of three unit operations: 1) pretreatment (pH and alkalinity reduction), ion exchange with two columns configured in series (multi-barrier perchlorate removal), and 2) posttreatment (restoration of pH and alkalinity). A general flow diagram of this process is shown in Figure 2.

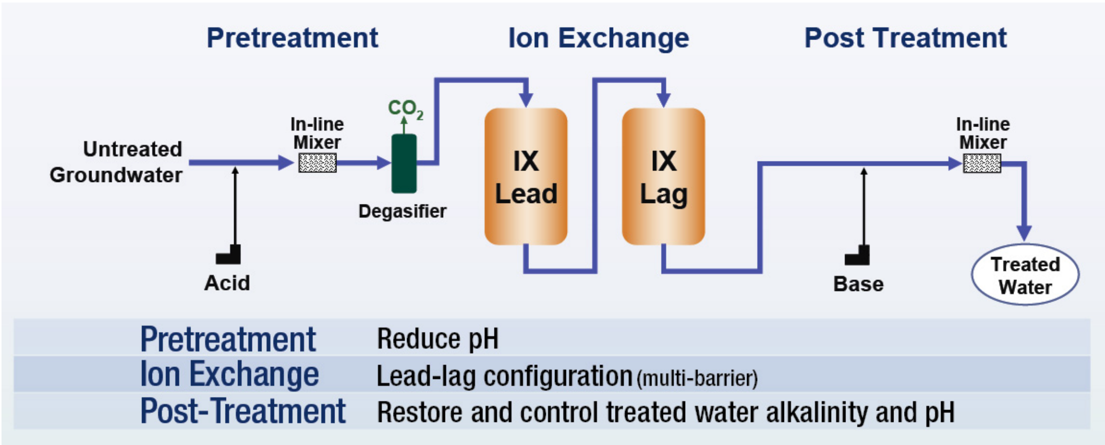

Figure 2. General process flow diagram.

The purpose of pretreatment is to prevent neutralization of WBA resin functional groups during ion exchange. This is accomplished by adding acid to the contaminated source water and reducing the pH. Specifically, the pH is reduced to below the pKa of the WBA resin (i.e., conditions at which 50% of the functional groups are protonated). During pH reduction, carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) alkalinity present in groundwater is converted to carbonic acid. Carbonic acid is in equilibrium with dissolved carbon dioxide (CO_2), which remains in solution at operating pressure and enables pretreatment and ion exchange to be accomplished using a single pumping operation. Ion exchange treatment is conducted in packed bed ion exchange vessels configured in series.

Posttreatment returns the treated water to acceptable levels of alkalinity and pH. The pH is controlled in the posttreatment neutralization process by the addition of base (i.e., sodium hydroxide or sodium carbonate). Alkalinity in the product water is controlled by the amount of dissolved CO_2 removed prior to or during neutralization. Conditions for pH and alkalinity are controlled to achieve product water that is neither scaling nor corrosive. This is determined by measuring pH, temperature, alkalinity, hardness, and total dissolved solids in the product water and calculating the Langelier Saturation Index (LSI).

2.1.2.2 WBA Ion Exchange Regeneration

When regeneration becomes necessary, the ion exchange vessels are configured so that the spent vessel (lead) is offline and the second vessel (lag) remains online. In this configuration, treatment continues while the spent vessel is regenerated. Regeneration is accomplished by increasing the pH of the spent resin to neutralize weak base functional groups. Another objective of regeneration is to minimize the volume of water generated for disposal. A predetermined volume of water is circulated through the resin bed for a fixed duration. Sufficient caustic (i.e., sodium hydroxide [NaOH]) is added to the water to neutralize the resin exchange sites and maintain pH above 12.0 throughout regeneration. Wastewater produced during regeneration is treated to remove perchlorate. This can be done by using a small volume of scavenger resin, or by biodegradation. When using the scavenger process, the perchlorate-free regenerating solution can then be discharged and the scavenger resin incinerated once capacity is reached. Schematics

showing the batch regeneration process and scavenger process are shown in Figure 3. A rinse using perchlorate-free water is conducted to remove residual perchlorate from the resin.

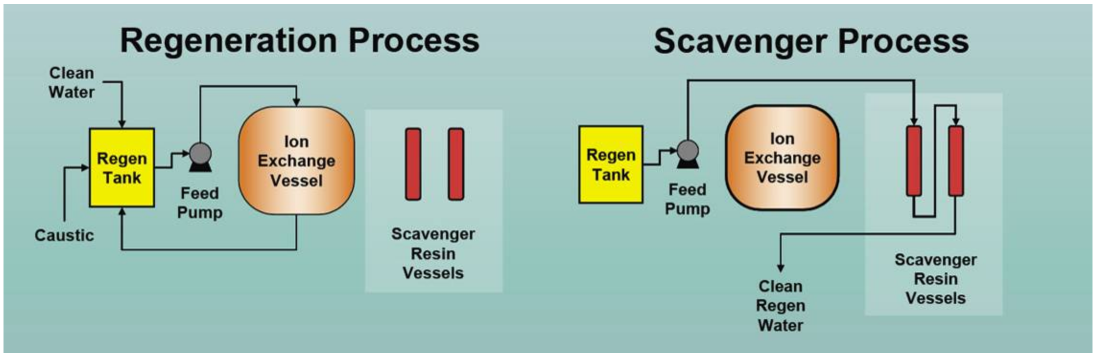

Figure 3. Regeneration and scavenging processes.

Once rinsing is complete, the WBA resin is restored to the ionized or protonated form by decreasing the pH of the resin. During protonation, water is circulated through the resin bed for a fixed duration. Sufficient acid is added to protonate the ion exchange sites and maintain pH equal to or less than 4.0. After protonation is complete, a rinse is conducted and the vessel is returned to service as the second treatment vessel in series (lag position). The spent protonating solution may be recovered, reused, or neutralized and discharged.

2.2 TECHNOLOGY DEVELOPMENT

Two pilot demonstrations of the WBA resin technology have been successfully completed. The first pilot demonstration was performing groundwater remediation at Redstone Arsenal, AL. The second pilot demonstration was conducting drinking water treatment at Fontana, CA. Both demonstrations were conducted and reported under ESTCP Project No. ER-0312, “Perchlorate Removal, Destruction, and Field Monitoring Demonstration.”

2.2.1 Groundwater Remediation – Redstone Arsenal, AL

Groundwater remediation was conducted at Redstone Arsenal, located near Huntsville, Alabama. The demonstration was performed over a period of 15 weeks during which treatment rates of 12, 18, and 24 bed volumes (BV) per hour (1.5, 2.25, and 3.0 gallons per minute [gpm]/cubic feet [ft^3] of resin, respectively) were evaluated. Well RS498, a six-inch extraction well, was selected as the groundwater source for the demonstration. Anion concentrations of the well were as follows: 1500 to 2200 ppb perchlorate; 4 parts per million (ppm) nitrate; 3 ppm sulfate; 4 ppm chloride, and 150 ppm bicarbonate. Performance of the WBA IX technology was assessed by collecting and analyzing groundwater samples before and after treatment. Five resin regeneration tests were performed to characterize regeneration efficiency. The spent regenerating solutions from these tests were used in perchlorate destruction and scavenging evaluations.

Results of the demonstration at Redstone Arsenal confirmed that perchlorate was reduced in the contaminated groundwater from >1500 ppb to well below the method detection limit (4 ppb) using USEPA Method 314.0. Regeneration of WBA resin was effectively and efficiently accomplished. The volume of spent regenerating solution was limited to less than 0.05% of the

volume of water treated. Two treatment processes for the spent regenerating solution were demonstrated including biodegradation and a zero-discharge approach using SBA scavenger resin. Both processes were effective in destroying or removing perchlorate to below the method detection limit. The regenerable WBA resin technology proved to be up to 50 times more efficient than brine-regenerable processes using SBA resins. In addition, O&M costs were projected to be less than $100 per acre-foot.

2.2.2 Drinking Water Treatment – Fontana, CA

As a result of the successful demonstration at Redstone Arsenal, a second demonstration for drinking water treatment in California was conducted at Plant F17 in Fontana, CA. Well F17-C water contained 8 ppb perchlorate; 11 ppm chloride; 31 ppm nitrate; 14 ppm sulfate; and 150 ppm bicarbonate. Six test periods were conducted during this demonstration. The minimum treatment rate was 24 BV per hour (3 gpm/ft^3). Four test periods were long cycle breakthrough tests (1, 2, 5, and 6). During regeneration of the spent column, the lag column remained online and treated water in a single column. The remaining two test periods (3 and 4) were short-cycle tests. In short-cycle tests, columns were regenerated after approximately one week on-line and before breakthrough. These short-cycle tests were conducted to maximize the number of regenerations per column and minimize the duration of the demonstration. The short-cycle tests were also used to evaluate perchlorate removal efficiency at higher specific flow rates (4 gpm/ft^3). Regeneration of spent resin and treatment of the spent regenerating solution using the zero-discharge scavenger process were conducted on-site.

The treatment capacity determined from this demonstration was 9,700 BVs. The treated water was below the method report limit for perchlorate (< 0.10 ppb) using ion chromatography-mass spectrometry/mass spectrometry (IC-MS/MS). Nitrosamines were analyzed using USEPA Method 521. N-nitrosodimethylamine (NDMA) was 2.6 parts per trillion (ppt) with a detection limit of 2 ppt. All other nitrosamines analyzed (including NDEA, n-nitrosodi-n-butylamine (NDBA), n-nitrosodi-n-propylamine (NDPA), n-nitrosomethylethylamine (NMEA), n-nitrosomorpholine (NMOR), NPIP, and n-nitrosopyrrolidine (NPYR)) were below the detection limit. The residual alkalinity of the treated water was controlled by varying the pH and using a combination of air/membrane stripping and calcite contacting. Treated water had a LSI near zero, which indicated that it had neither corrosive nor scaling tendencies. Five resin regenerations were accomplished using 3 BVs of regenerant solution, or approximately 0.03% of the treated water. The spent regenerating solution was successfully treated using the zero-discharge scavenger resin approach to remove perchlorate to below method reports limits. The scavenger approach cost less than $5 per acre-foot to implement based on conditions at the Fontana demonstration site.

2.3 ADVANTAGES AND LIMITATIONS OF THE WBA IX TECHNOLOGY

2.3.1 Technology Comparisons

Three technologies are currently used commercially for remediating perchlorate-contaminated groundwater: 1) biodegradation, 2) ion exchange using SBA regenerable resins, and 3) ion exchange using non-regenerable or disposable SBA resins. The WBA resin technology takes advantage of the performance, favorable public perception, and regulatory acceptance of ion

exchange while minimizing the liabilities of current ion exchange systems. These liabilities include: 1) high cost of perchlorate-selective resins currently in use, 2) large volume of residuals generated by regenerable systems, 3) difficulty and high cost of treating residuals, and 4) resin replacement and incineration costs for non-regenerable systems.

2.3.2 Technology Advantages and Limitations

Weak base, perchlorate-selective resins do not have the treatment capacity of strong base, perchlorate-selective, single-use resins. Even so, overall cost savings may be substantial since the WBA resins can be economically regenerated. Pretreatment and posttreatment steps required for the WBA resin process do add process complexity compared to single-use ion exchange systems; however, the complexity is not greater than other commercial, regenerable ion exchange technologies. Pretreatment and posttreatment unit operations are very straight-forward pH control processes.

Water quality parameters including alkalinity, hardness, perchlorate concentration, sulfate concentration, and treated water alkalinity affect cost and performance. The amount of acid required to achieve operating pH is directly proportional to feed water alkalinity and; therefore, pretreatment cost. Perchlorate concentration dictates the resin treatment capacity and regeneration frequency that affects regeneration cost. In addition, perchlorate concentration and regeneration frequency impact the amount of spent regenerating solution and treatment cost. Hardness and desired alkalinity of treated water affect the caustic requirement for neutralization, which affects neutralization cost. Competing ions such as nitrate will also impact treatment performance by driving a need for more frequent regenerations. Competing ion concentration is a limiting factor for all ion exchange technologies.

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3.0 PERFORMANCE OBJECTIVES

The objective of this effort was to demonstrate a large-scale (1000 gpm) drinking water treatment system for perchlorate removal using the WBA process. This treatment system was designed specifically for treating drinking water from Rialto No. 3. Due to the level of perchlorate concentration and presence other contaminants, this particular well is considered an extremely impaired source as defined by the CDPH 97-005 Policy Memorandum.

During the demonstration, data was collected to evaluate perchlorate removal performance, regeneration efficiency, ease of operation, and O&M costs. Based on data from the previous pilot demonstrations, it was anticipated that O&M costs would be < $150/acre-foot. Upon completion of demonstration testing, there is an option for ownership of the treatment system to be transferred to the City of Rialto.

Performance of the WBA system was evaluated by collecting and analyzing samples for perchlorate during ion exchange, regeneration, and treatment of residuals. Analytical results were used to assess and predict treatment performance of the WBA resin at the conditions tested. Operational data including flow rate, system pressure, pH, and consumption of chemicals and power were recorded and analyzed to validate operating performance and predict O&M costs. Specific quantitative and qualitative performance objectives for this demonstration are summarized in Table 1. Subsequent sections provide details for each performance objective identified.

Table 1. Performance objectives.

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives			
1. Meet perchlorate regulatory standard	Perchlorate concentration in treated water.	< DLR (4 ppb)	< 1.5 ppb (average= 0.61 ppb)
2. Demonstrate posttreatment capability	Treated water characteristics including pH, total dissolved solids, alkalinity, hardness, and temperature to be used for calculating LSI.	0 < LSI < 1.0 (i.e., non-corrosive & non-scaling)	No samples met requirement
3. Minimize process waste	Volume of spent solutions collected during regeneration and volume of water treated prior to regeneration.	≤ 0.07 vol% residual	≤ 0.07 vol% residual
4. Demonstrate treatment of spent regenerating streams	Perchlorate concentration in treated spent regenerant following treatment using strong base anion resin (scavenging).	≤ 100 ppb perchlorate	≤ 2.5 ppb perchlorate
5. Determine perchlorate bleed from regenerated vessel	Perchlorate concentration in regenerated vessel effluent following a regeneration cycle.	< DLR (4 ppb)	All samples ≤ 0.27 ppb perchlorate
6. Treatment flow rate	Log of operational flow rate (gpm) during ion exchange.	≥ 2.5 gpm/ft^3	≤ 2.5 gpm/ft^3 (2.29 gpm/ft^3)
7. Validate and report operating cost	Tracked—consumable chemical and resins, misc. supply, and waste disposal costs. Untracked—electrical and labor requirements.	< $150 /acre-ft	Actual= >$398/acre-foot Normalized= $229/acre-foot
8. System scalability	Actual regeneration time required for offline vessel; anticipated regeneration frequency.	System can support two additional ion exchange treatment trains and expand to 3000 gpm.	System will support two additional trains
Qualitative Performance Objectives			
9. Model/predict WBA resin capacity for drinking water application	Perchlorate, nitrate, sulfate, and chloride concentrations in groundwater and in treated water exiting lead vessel.	Provide a treatment capacity, in BVs, before regeneration is required.	≥ 9000 BVs
10. System control during treatment and regeneration cycles	Feedback from field technician on ability to use programmable logic control system to effectively monitor and control system operations such as flow, pressure, and pH during demonstration treatment and regeneration.	A single field technician able to effectively take measurements and control system. System control features and interlocks operate as designed. System startup following shutdown initiates as designed.	Normal operations one operator required; during regeneration, two operators required

4.0 SITE DESCRIPTION

4.1 SITE LOCATION AND HISTORY

The City of Rialto, CA is located in San Bernardino County at the southern base of the San Gabriel Mountains with topography ranging from a low of 1120 feet to a high of 1520 feet above sea level. The 22 square mile city is bounded by San Bernardino and Colton on the east and southeast and by Fontana and unincorporated Bloomington on the west and southwest.

The northern two-thirds of the City of Rialto overlies the Rialto-Colton Groundwater basin. The City of Rialto currently depends on groundwater from this basin and other nearby groundwater basins for approximately 90% of its annual water supply. Groundwater in the basin flows southeast from the northwest near the former Rialto Ammunition Storage Point (RASP) site, toward the Santa Ana River.

The RASP property was used for munitions storage by the U.S. Army during World War II. Following inactivation of the RASP in late 1945, and over several years, the property was leased, subdivided, and sold to commercial activities. One resulting activity is the Mid-Valley Sanitary Landfill (MVSL), which has been operated by the County of San Bernardino since 1958. This property consists of approximately 448 acres of which 222 acres are in use for waste disposal activities. In 1990, the County purchased the northeast area of its current property, which contained storage bunkers that were known to have housed explosives, chemicals, propellant, oxidizers, and fireworks. The County demolished these bunkers in 1998-1999 and a portion of this area is currently used by a sand and gravel business in accordance with an agreement between the County and the business. In 1997, the County sampled 23 monitoring wells in the MVSL monitoring system for perchlorate. Only one well had a detectable concentration of perchlorate and it was less than five ppb. In 2001, perchlorate concentration of one of the MVSL monitoring wells increased significantly to 250 ppb. As a result, the County increased its monitoring for perchlorate in existing monitoring wells. The County also initiated an assessment of the possible perchlorate sources on its property by analyzing soil samples and process water samples generated by the sand and gravel business. The County found that the northeast area of its property purchased in 1990 may be a source of perchlorate contamination in the groundwater.

The municipal well Rialto No. 3 is located near the City of Rialto's municipal airport and is owned and operated by the City of Rialto. This well is downgradient of the MVSL property owned by the County and has been impacted by perchlorate and volatile organic carbon (VOC) contamination. This well has historically represented approximately 15% of the City's demand and is considered an important facility for the City's water system. In 2003-2004, the Santa Ana Regional Water Quality Control Board (RWQCB) issued cleanup and abatement orders that required the County to cleanup and abate perchlorate discharges at and from its property as well as provide replacement water.

Presently at Rialto No. 3, the County has in place a 2000 gpm, single-use ion exchange system for perchlorate treatment. This treatment system is intended to intercept, contain, and treat groundwater contaminated with perchlorate and provide the replacement water necessary to fulfill the RWQCB cleanup and abatement order(s). Treatment system upgrades have been completed including installation of two additional extraction wells to enhance plume

containment; adding a 100,000 gallon drinking water reservoir to store water before it is treated by the permitted treatment system; adding ultraviolet (UV) disinfection to disinfect groundwater before it is introduced to the ion exchange vessels; and adding granulated activated carbon (GAC) vessels to remove VOC that has been detected in upstream monitoring wells. The WBA demonstration system treated water upstream of the UV and GAC systems.

4.2 SITE GEOLOGY/HYDROGEOLOGY

Groundwater in the Rialto-Colton basin occurs within alluvial sediments at depths ranging from more than 400 feet below ground surface (bgs) near Rialto No. 3 to less than 100 feet bgs closer to the mountain front. Groundwater elevation data collected by the U.S. Geological Survey (USGS) indicates that groundwater in the northern and central portions of the basin flows to the south and southeast under a hydraulic gradient of about 0.3% to 1.2%. Upgradient of Rialto No. 3, groundwater elevation data obtained historically for monitoring wells located near the MVSL indicate steeper hydraulic gradients ranging from of 1.0% to 1.7% (GLA, March 2006).

Investigations and literature reviews conducted by the County indicate the presence of three laterally-continuous aquifers within the USGS's "middle hydrologic unit" in the Rialto-Colton Basin. These laterally continuous aquifers include an upper unconfined aquifer that is currently dry, an intermediate partially confined aquifer, and a deep regional confined aquifer that provides much of the groundwater that is pumped in the area by municipal supply wells. The three aquifers are separated by low-permeability aquitards that generally range in thickness from only a few feet to over 30 feet. The groundwater velocity is estimated to be approximately 0.5 to five feet per day.

4.3 CONTAMINANT DISTRIBUTION

A groundwater monitoring program is in place to monitor the lateral and vertical extent of perchlorate and VOC contamination upstream of Rialto No. 3. The monitoring program consists of quarterly groundwater sampling of monitoring wells located in the contamination plume impacting Rialto No. 3, also known as the Western Plume. Wells sampled to fulfill the monitoring program include: seven near-field monitoring wells (M-1, M-2, M-3, M-4, M-5, M-6, and N-14); eight plume-wide monitoring wells (F-6A, N-7, N-8, N-10, N-11, N-12, N-13, and N-15); nine piezometer monitoring stations (F-3, F-6, N-1, N-2, N-3, N-4, N-5, N-6, and N-9); and three west-side cluster monitoring wells (N-16, N-17, and N-18). The location of the MVSL property, the approximate limit of the Western Plume, the location of wells sampled for the groundwater monitoring program, and the location of Rialto No. 3 is shown in Figure 4. This map was included in the Spring 2008 monitoring results reported by GeoLogic Associates, a consultant supporting the County of San Bernardino.

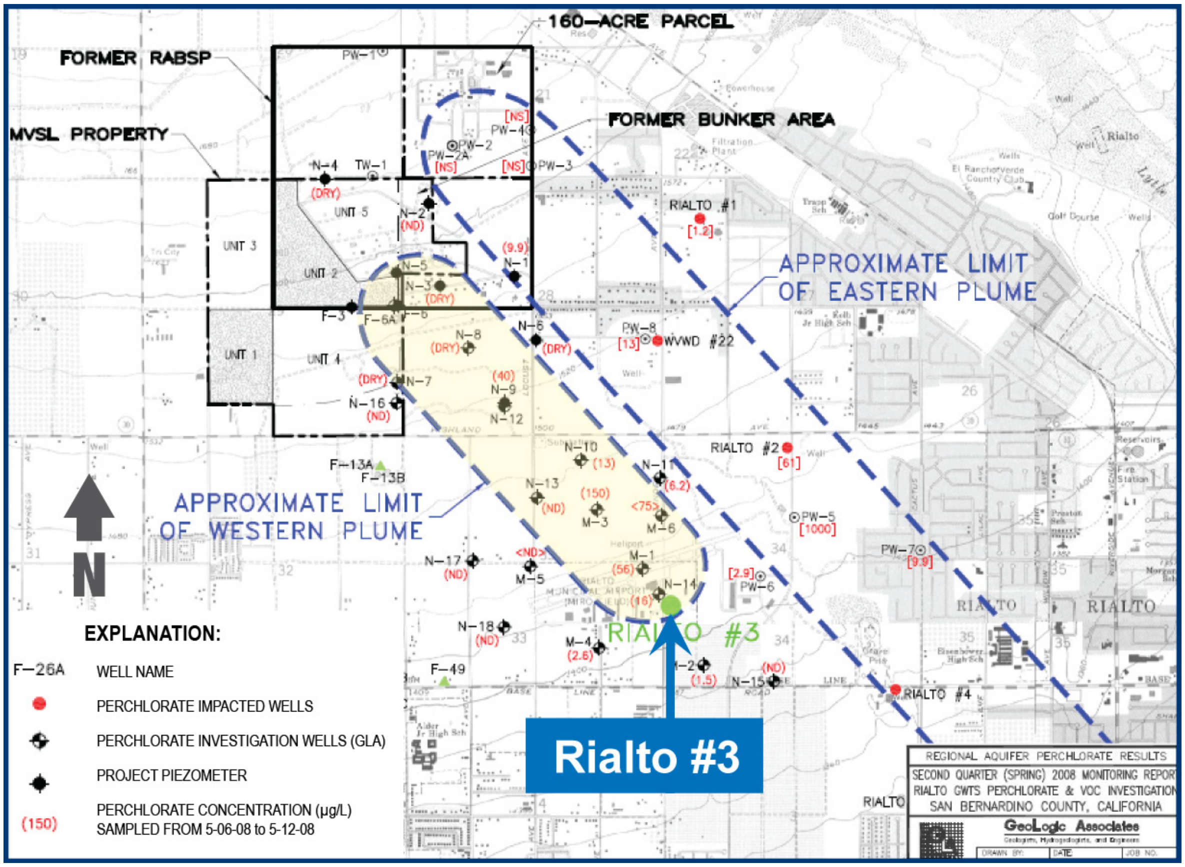

Figure 4. Locations of wells in the western plume in relation to Rialto No. 3.

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5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

This section provides a broad overview of the experimental design to be used to evaluate the technology based on performance objectives. Specific details of the experimental design including sample collection, quality controls and procedures, and data evaluation are provided in the following sections.

5.2 BASELINE CHARACTERIZATION ACTIVITIES

A water monitoring program has been in effect for Rialto No. 3 and monitoring wells since 2006. A report is generated quarterly summarizing the analytical results. The results from the June 22, 2010 report of the raw water from Rialto Well No. 3 are presented in Table 2.

Table 2. Analytical results – historical summary data for well No. 3 Rialto.

Analyte	Units	Avg. Value
Anions		
Nitrate-Nitrogen	mg/L	4.64
Perchlorate	µg/L	15.14
Sulfate	mg/L	13.36
Volatile Organic Compounds (USEPA 524.2)		
Bromochloromethane	µg/L	0.19
Bromodichloromethane	µg/L	0.42
Bromoform	µg/L	0.36
Chloromethane	µg/L	0.26
Dibromochloromethane	µg/L	1.09
Trichloroethene	µg/L	0.36
Total Trihalomethanes	µg/L	3.83
Bacteriological		
Heterotrophic Plate Count	CFU/mL	29.9

5.2.1 Available Characterization Data

The county of San Bernardino executes a groundwater monitoring program monthly, quarterly, and annually. During this program, approximately 26 groundwater monitoring wells or piezometers are sampled to characterize the groundwater and contamination plume. Relative to the location of Rialto No. 3, these wells and piezometers are positioned near-field, plume-wide, and on the west side. Samples are analyzed for one or more of the various constituents including perchlorate, VOC compounds, alkalinity, bicarbonate, carbonate, chloride, hardness (calculation), hydroxide, nitrate, sulfate, total dissolved solids, and metals. Wells from which water could not be sampled (i.e., the well is dry) are identified in the data report.

Data collected from the most up to date groundwater monitoring report were reviewed prior to initiating the demonstration for any anomalies and to facilitate characterization of the groundwater properties approaching Rialto No. 3. Of most interest for this demonstration were the near-field wells located directly upstream from Rialto No. 3. These wells include N-14, M-1,

and M-3, which are approximately 325 ft, 900 ft, and 2,440 ft directly upstream from Rialto No. 3, respectively.

5.2.2 Groundwater Sampling

In addition to having the available plume characterization data, groundwater from Rialto No. 3 was sampled and analyzed prior to startup of the WBA demonstration system. This groundwater was analyzed for perchlorate, nitrate, sulfate, chloride, and general mineral and physical properties used to determine scaling potential. These water quality characteristics were used not only to assist in determining operational parameters, but also to establish the baseline for evaluating performance objectives identified in Section 3.0. Throughout the demonstration, Rialto No. 3 was sampled several times each month and analyzed by either ARA or by a certified laboratory.

5.3 TREATABILITY OR LABORATORY STUDY RESULTS

Treatability and laboratory studies were previously performed under ESTCP Project No. ER-0312, "Perchlorate Removal, Destruction, and Field Monitoring Demonstration."

5.4 FIELD TESTING

5.4.1 Functional Testing

All vessels, tanks, pumps, pipes and valves, and sensors and controls were inspected for structural integrity and function. Leak testing of tanks, pumps, and valves were performed by filling tanks with potable water or groundwater and inspecting the system for leaks while operating individual pumps and valves. Equipment items (i.e., pumps, air compressor, etc.) and instrumentation (i.e., pH probes, level sensors, etc.) were functionally/operationally tested and calibrated. Water used for leak testing was drained into the infiltration basin.

Functional testing was previously completed during the fall of 2010 under ESTCP Project No. ER-0312, "Perchlorate Removal, Destruction, and Field Monitoring Demonstration."

5.4.2 Startup Testing

Following functional testing, the system was operated under scenarios which tested system operation and control. All system alarms and interlocks in the programmable logic controller (PLC) logic were tested to ensure that the system operated as designed in a controlled and reliable manner.

Startup testing was previously completed during the fall of 2010 under ESTCP Project No. ER-0312, "Perchlorate Removal, Destruction, and Field Monitoring Demonstration."

5.4.3 System Disinfection

Prior to delivering water from the WBA demonstration system to the 100,000 gallon reservoir feeding the existing perchlorate treatment system, the vessels, tanks, and pipes were disinfected. A subcontractor was hired to disinfect the system according to the American Water Works

Assoication (AWWA) standard C653-03 "Disinfection of Water Treatment Plants." Disinfection was previously completed during the fall of 2010 under ESTCP Project No. ER-0312. Due to the length of time the system had been in standby awaiting for various approvals (approximately 6-7 months), Bac-T analyses were performed to determine whether further disinfection was required prior to the beginning of the demonstration. All analytical results came back negative and no further disinfection was required.

5.4.4 System Demonstration

5.4.4.1 Test Matrix

Due to unexpected delays, testing was reduced to four test periods. These delays came in the form of delayed approval by the City of Rialto for amending the current treatment permit, the time required for CDPH to review the permit amendment, and delays in a resin change out (May-July 2011) for the existing SBA system. ARA returned to the site on July 12, 2011, and performed a week of system re-preparation and re-checkout. Demonstration and system start up took place on July 18, 2011. The demonstration continued until December 08, 2011, when it was terminated due to budgetary constraints. A Gantt chart showing the actual schedule is shown in Figure 5.

Additional delays and problems occurred throughout each test period that lengthened the overall time of the demonstration. These delays and problems presented themselves most often as difficulties obtaining groundwater from Rialto No. 3, but also with operation of the soda ash posttreatment system. The test plan performed is shown in Table 3.

Table 3. WBA IX test matrix.

Test Period	Lead Vessel	Actual Days of Operation	Lead Column			Gallons Treated (MG)
			BV Treated[1]	ClO_4 Conc. (ppb)	% Breakthrough	
1 [1]	WBA-301	3.1	1339	1.2	13	3.51
2 [1]	WBA-302	5.5	2261	1.4	16	5.92
3 [1]	WBA-301	9.3	4081	2.8	31	10.69
4 [2]	WBA-302	16.5	7269	4.4	49	19.03
TOTALS:		**34.4**	**14,950**			**39.15**

[1] The low volume of BVs treated during the first three test periods were due to early termination of testing to meet project regeneration objectives

[2] The fourth test was terminated early due to operational problems

MG = ?????

During each test period, there were six operating modes for each ion exchange vessel: 1) IX operation/water treatment; 2) regeneration of the lead column; 3) scavenger treatment of regeneration waste; 4) regeneration rinse; 5) protonation; and 6) protonation rinse. Figure 6 is a diagram illustrating the order of these operating modes and provides a brief configuration description for the lead and lag vessels.

ID	Task Name	Duration	Start	Finish
1	Rialto 3 WBA IX Demonstration	573 days	Fri 3/18/11	Mon 12/31/12
2	Original Contract Award Date	0 days	Fri 3/18/11	Fri 3/18/11
3	Original Contract	367 days	Fri 3/18/11	Sun 3/18/12
4	Demonstration Plan (Draft)	0 days	Fri 4/29/11	Fri 4/29/11
5	CDPH Pretreatment Permit	38 days	Mon 4/18/11	Wed 5/25/11
6	Demonstration Plan (Final)	0 days	Mon 7/11/11	Mon 7/11/11
7	No Cost Extension Award	0 days	Fri 3/16/12	Fri 3/16/12
8	No Cost Contract Extension	209 days	Fri 3/16/12	Mon 12/31/12
9				
10	WBA IX Demo Testing	232 days	Wed 7/13/11	Wed 2/29/12
11	Startup Testing	5 days	Wed 7/13/11	Sun 7/17/11
12	Test Period 1	7 days	Mon 7/18/11	Sun 7/24/11
13	Regen 1	3 days	Mon 7/25/11	Wed 7/27/11
14	Test Period 2	8 days	Mon 7/25/11	Mon 8/1/11
15	Regen 2	2 days	Mon 8/1/11	Tue 8/2/11
16	Test Period 3	41 days	Mon 8/1/11	Sat 9/10/11
17	Regen 3	2 days	Sat 9/10/11	Sun 9/11/11
18	Test Period 4	90 days	Sat 9/10/11	Thu 12/8/11
19	End of Testing	0 days	Thu 12/8/11	Thu 12/8/11
20	Decommissioning	8 days	Wed 2/22/12	Wed 2/29/12
21				
22	ESTCP Reporting	555 days	Fri 4/15/11	Tue 1/15/13
23	Draft Final Report	0 days	Tue 5/15/12	Tue 5/15/12
24	Draft Cost & Performance Report	0 days	Fri 6/15/12	Fri 6/15/12
25	Final Report	0 days	Tue 7/17/12	Tue 7/17/12
26	Cost & Performance Report	0 days	Tue 7/31/12	Tue 7/31/12

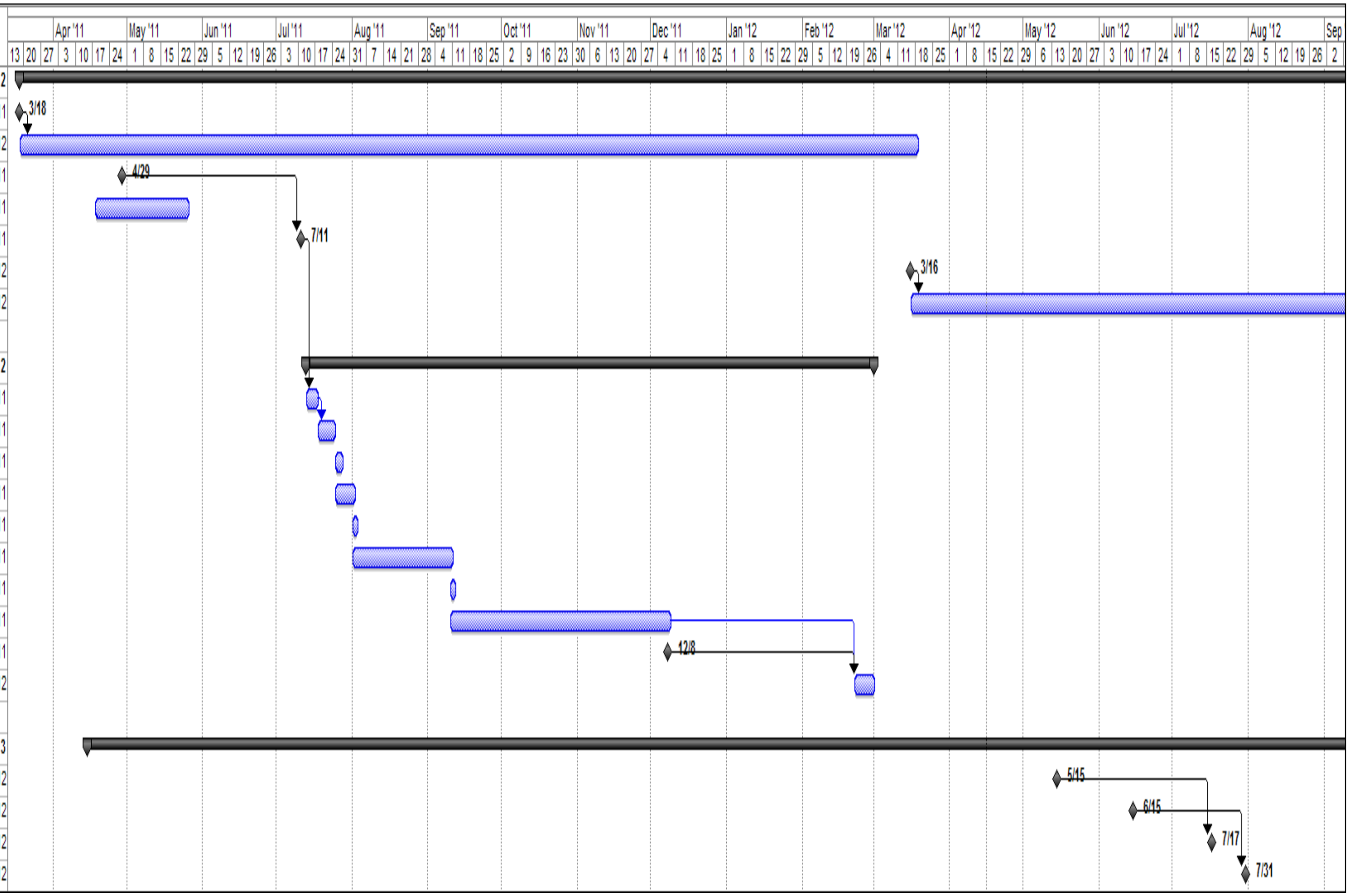

Figure 5. Rialto 3 WBA IX testing.

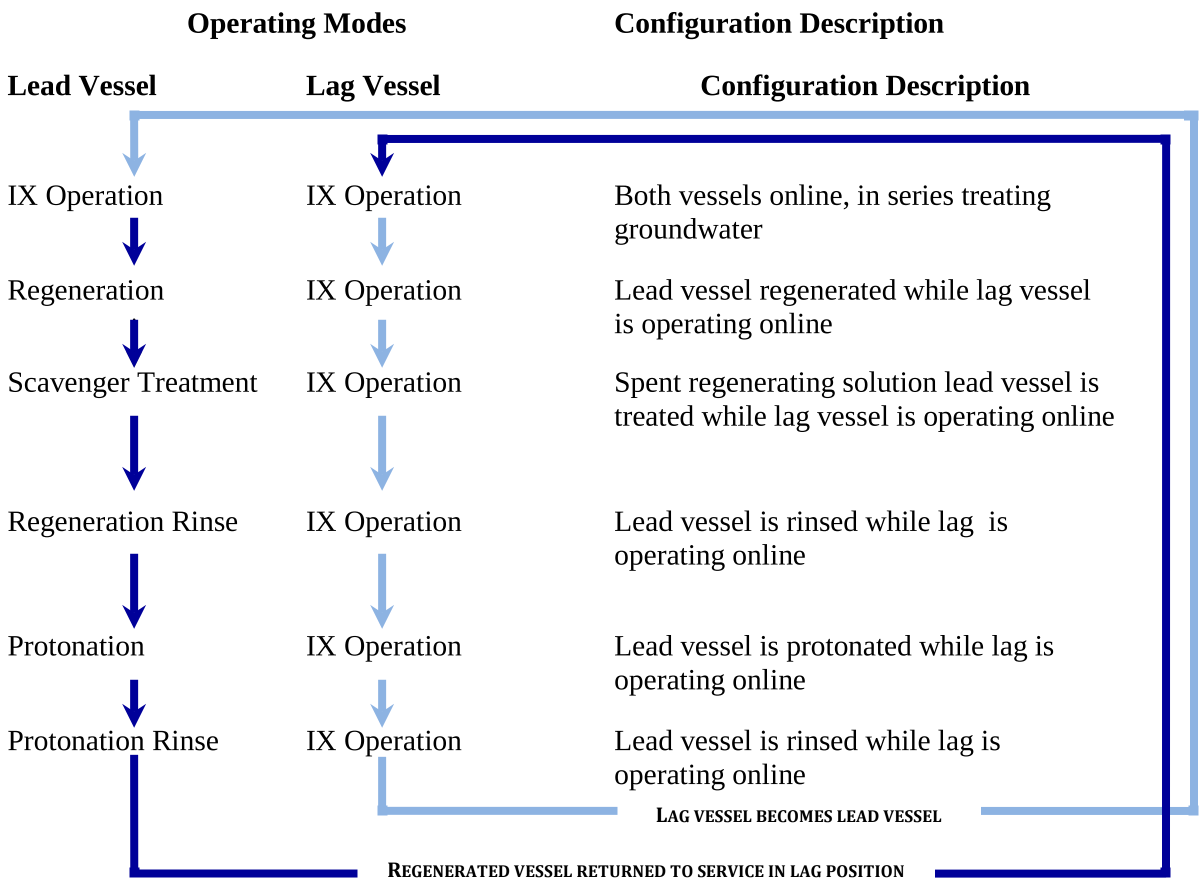

Figure 6. Configuration description of operational steps.

Each test period was defined as the point in time when flow was initiated through the newly regenerated vessel in the lead position until the vessel was taken offline for regeneration. Data from models based on the Fontana demonstration (ESTCP Project No. ER-0312) estimates that each WBA vessel will treat approximately 9000 BVs of water from Rialto No. 3 prior to perchlorate breakthrough. The first two test periods were intentionally reduced in order to accomplish the operation-regeneration cycles in a short period of time. This was performed in an attempt to enable the resin to reach homeostatic performance, overcoming the performance influences caused by virgin-resin effects. The third test period was intended to operate the resin to near breakthrough conditions. For this demonstration, breakthrough was defined as the amount of BVs treated when the perchlorate concentration of the lead vessel effluent reaches 50% of the perchlorate concentration of the groundwater influent. The calculated BVs required for breakthrough was predicted to be 9000 BVs. The fourth test period was intended to demonstrate breakthrough, but was not completed due to operational difficulties and budgetary constraints.

5.4.5 System Shutdown and Demobilization

The demonstration ended on December 08, 2011, due to schedule and budget constraints. ARA returned to the site February 22, 2012, to begin demobilization. Both ion exchange vessels were regenerated offline manually. At completion of regeneration, both vessels were drained and the

resin left at pH >12.0 to prevent any biological growth during long term storage. The Liqui-Cel membrane pretreatment system was isolated and completely drained. All chemical supply lines were back flushed to a sump and drained to the waste storage tank for disposal. Each of the chemical storage vessels and regeneration vessels were also drained to the waste storage tank, rinsed, re-drained to waste storage, and isolated. The A530E SBA resin used for scavenging perchlorate from the spent regenerant was removed from the scavenger vessels by a certified contractor (Baker/Purolite) and landfilled. All soda ash was removed from the package soda ash posttreatment system and placed in containers for disposal. This soda ash and excess bags of soda ash were disposed of by a certified waste hauler (K-Vac Environmental, Rancho Cucamonga, CA). The soda ash dissolver tank was drained and rinsed thoroughly to the waste storage tank. The soda ash feed system was also disassembled and all equipment rinsed down with potable water into a sump and drained to waste storage. All liquids from the waste storage tank were neutralized and disposed of at the San Bernardino SARI line by the certified waste handler (K-Vac Environmental) under ARA's disposal permit.

All data collected on the data acquisition system (DAQ) was downloaded onto a thumb drive and secured. The data acquisition system and PLC were switched off and system power was de-energized at the breaker panels. All pH probes were thoroughly cleaned, rinsed with distilled water, and placed in individual storage containers filled with pH 7.0 buffer solutions. Spare parts and equipment to be left onsite were stored in boxes on shelves in the control building. The WBA resin ion exchange system will remain in standby mode until final disposition is determined by San Bernardino County and the City of Rialto.

5.5 SAMPLING METHODS

All demonstration sampling was conducted by ARA personnel. A comprehensive sampling plan titled "Demonstration of Perchlorate Removal at Rialto No. 3 using 1000 gpm WBA Resin Technology-Performance Objective Plan" was submitted to CDPH April 2011 for pretreatment permit approval. This plan covers sampling, calibration of analytical equipment, quality assurance sampling, and sample documentation and has been attached as Appendix B. A summary of the analytes, methods, sample descriptions, and number of samples pulled during both the water treatment cycle and the regeneration cycle for each test period are shown below in Tables 4 and 5. The number of samples does not include duplicates or quality assurance/quality control samples collected and analyzed in accordance with the Quality Assurance Project Plan.

Table 4. Sampling summary for WBA IX demonstration during the treatment cycle.

Test Period	Sample Description	ARA Laboratory		Weck Laboratories				
		ClO_4^- (USEPA314.0)	Anions (USEPA300.0)*	ClO_4^- (USEPA314.0)	ClO_4^- (USEPA331.0)	Anions (USEPA300.0)*	LSI Group**	Biological
1	GW Feed	6	2	1		1	1	1
	Lead A	6	2	1	1			1
	Lag B	6	2					
	FTGW	6	2	1	1	1	1	1
2	GW Feed	6	2	4			1	2
	Lag A	6	2					1
	Lead B	6	2		2			1
	FTGW	6	2		2	1	2	2
3	GW Feed	14	5	4			1	
	Lead A	14	5		2	1		2
	Lag B	14	5		1			
	FTGW	14	5		6	4	5	2
4	GW Feed	24	9	1			1	
	Lag A	24	9		1			
	Lead B	24	9		7			3
	FTGW	24	9		13	6	5	3
	TOTALS:	**200**	**72**	**12**	**36**	**14**	**17**	**19**

*Anions include nitrate, sulfate, and chloride

**LSI Group includes pH, alkalinity, total dissolved solids, calcium, and temperature

Table 5. Sampling summary for WBA IX demonstration during the regeneration cycle.

Test Period	Sample Description	ARA Laboratory		Weck Laboratories				
		ClO_4^- (USEPA314.0)	Anions (USEPA300.0)*	ClO_4^- (USEPA314.0)	ClO_4^- (USEPA331.0)	Anions (USEPA300.0)*	LSI Group**	TDS
1	Regeneration	3	3	1		1	1	
	Regen Rinse	13	10		4	1	1	
	Lead Scavenger	1	1					
	Lag Scavenger	1	1		1	1	1	
	Protonation	1		1		1	1	
	Protonation Rinse	13	11		2	1	1	
2	Regeneration	3	3	1		1		
	Regen Rinse	12	12		3	1	1	
	Lead Scavenger	1	1					
	Lag Scavenger	1	1	1		1		1
	Protonation	3		1		1		1
	Protonation Rinse	8	8		3	1		1
3	Regeneration	3	3	1		1		1
	Regen Rinse	16	16		4	1	1	
	Lead Scavenger	1	1					
	Lag Scavenger	1	1	1		1		1
	Protonation	3		1		1	1	
	Protonation Rinse	8	8		2	1	1	
	TOTALS:	**92**	**80**	**8**	**19**	**15**	**9**	**5**

*Anions include nitrate, sulfate, and chloride

**LSI Group includes pH, alkalinity, total dissolved solids, calcium, and temperature

TDS = total dissolved solids

The analytical methods along with specific containers, preservatives and maximum holding times used during the demonstration are presented in Table 6.

Table 6. Analytical methods used during the WBA IX demonstration.

Analyte	Method	Container	Preservative	Holding Time
Perchlorate, IC	USEPA 314.0	HPDE	<4 °C	28 days
Low-Level Perchlorate, LC/IC/MS/MS	USEPA 331.0	HPDE	<4 °C	28 days
Nitrate, as NO_3	USEPA 300.0	HPDE	<4 °C	2 days
Sulfate	USEPA 300.0	HPDE	<4 °C	28 days
Chloride	USEPA 300.0	HPDE	<4 °C	28 days
pH	USEPA 150.1	HPDE	<4 °C	15 minutes
Alkalinity (as $CaCO_3$)	SM 2320B	HPDE	<4 °C	14 days
Total Dissolved Solids (TDS)	SM 2540C	HPDE	<4 °C	7 days
Calcium, Total	USEPA 200.7	HPDE	<4 °C, Nitric Acid	6 months
Langelier Saturation Index/Corrosivity**	SM 2330B	HPDE	<4 °C	14 days
Nitrosamines	USEPA 521	Amber Glass	<4 °C	365 days
Total Coliform/E. coli, P/A	SM 9223	Sterile Polyethylene	<4 °C, Sodium Thiosulfate	30 hours

*All samples were in aqueous matrix
**LSI/Corrosivity includes pH, alkalinity, total dissolved solids, calcium, and temperature

Samples were analyzed for perchlorate, other inorganic anions, and total dissolved solids at ARA's in-house laboratory. Select samples were split and shipped to Weck Laboratories for external analysis of perchlorate, inorganic anions, LSI, and other general mineral and physical analyses. Biological testing required by CDPH was performed by Clinical Laboratories. The address of each laboratory is listed below:

In-House Analyses:
Applied Research Associates, Inc.
430 West 5th Street, Suite 700
Panama City, FL 32401
Phone: 850-914-3188

External Analyses:
Weck Laboratories, Inc.
14859 East Clark Avenue
City of Industry, CA 91745
Phone: 626-336-2139
NELAP #: 04229CA

Clinical Laboratory of San Bernardino, Inc.
21881 Grand Terrace Road
Grand Terrace, CA 92313
Phone: 909-825-7693
ELAP #: 1088

5.6 SAMPLING RESULTS

5.6.1 Perchlorate Analysis

All fully treated water samples analyzed for perchlorate during each test period were less than the detection limit for reporting (DLR) of 4 ppb. During the demonstration, there were several

unexpected shutdowns due to water supply problems with Rialto No. 3 or from other perturbations. The WBA IX system was restarted on each occasion with no treated water perchlorate concentrations exceeding the DLR of 4 ppb. ARA laboratory results are shown below in Figure 7. Both groundwater and treated groundwater samples were analyzed using USEPA Method 314.0 (IC).

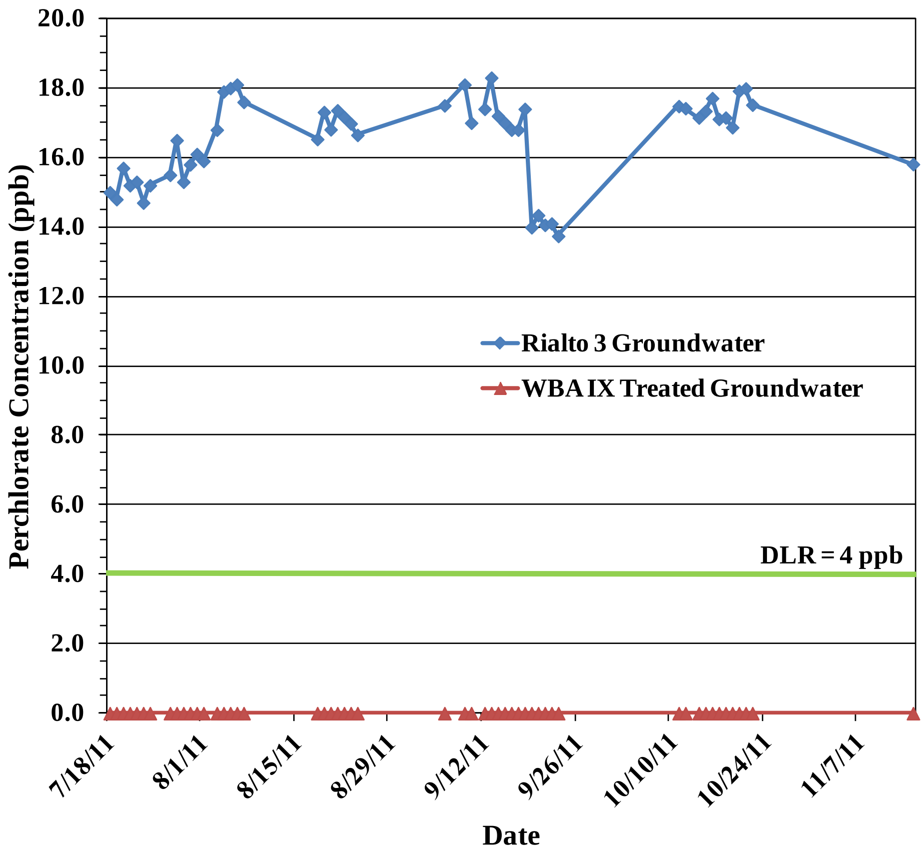

Figure 7. ARA laboratory perchlorate results for test periods 1-4.

Results from Weck Laboratories (City of Industry, CA) are shown below in Figure 8. These results confirm the ARA results above. All groundwater samples from Rialto No. 3 were analyzed using USEPA 314.0 (IC), while all fully treated water samples were analyzed using USEPA 331.0 (LC/IC/MS/MS).

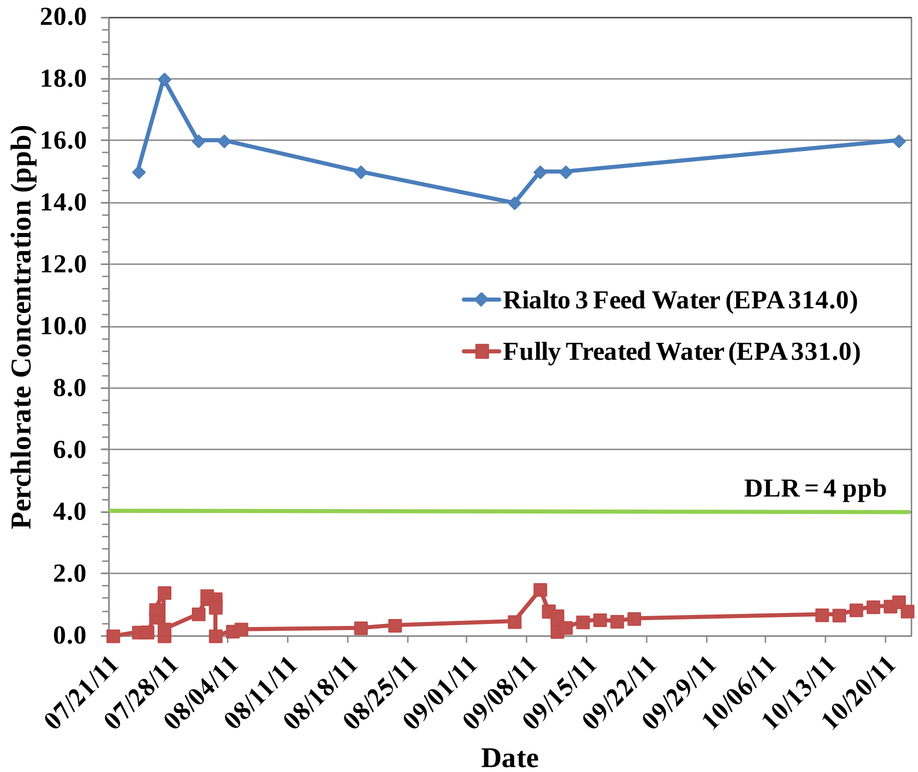

Figure 8. Certified laboratory perchlorate results for test periods 1-4.

5.6.2 Posttreatment—Langelier Saturation Index (LSI)

The performance objective for posttreatment was to control and adjust pH and alkalinity of the fully treated water to acceptable levels with regard to corrosiveness or scaling tendencies prior to distribution. The LSI was used as the measure of posttreatment success. This index is a calculated number used to predict the calcium carbonate ($CaCO_3$) stability of water; that is, whether a water sample will precipitate, dissolve, or be in equilibrium with $CaCO_3$. The data required to calculate LSI includes alkalinity (mg/L as $CaCO_3$), pH, total dissolved solids (mg/L TDS), calcium hardness (mg/L as $CaCO_3$), and water temperature (°C). If water has an LSI of > 1.0, scale tends to form; conversely, if water has an LSI of -1.0, it is considered corrosive (i.e., dissolves $CaCO_3$). In practice, water between -0.5 and 0.5 tends to be neither scaling, nor corrosive. For this demonstration, the objective was considered successful if 95% or more of the samples were between and LSI of 0 and 1.0.

Samples of fully treated water were analyzed by Weck Laboratories and the resulting data was used to calculate the LSI for each sample. Of the 18 samples taken during the demonstration, no samples measured at 20°C met our performance objective of having an LSI between 0 and 1.0. Only four samples (22%) measured at 60°C met that objective. Results are shown below in Figure 9.

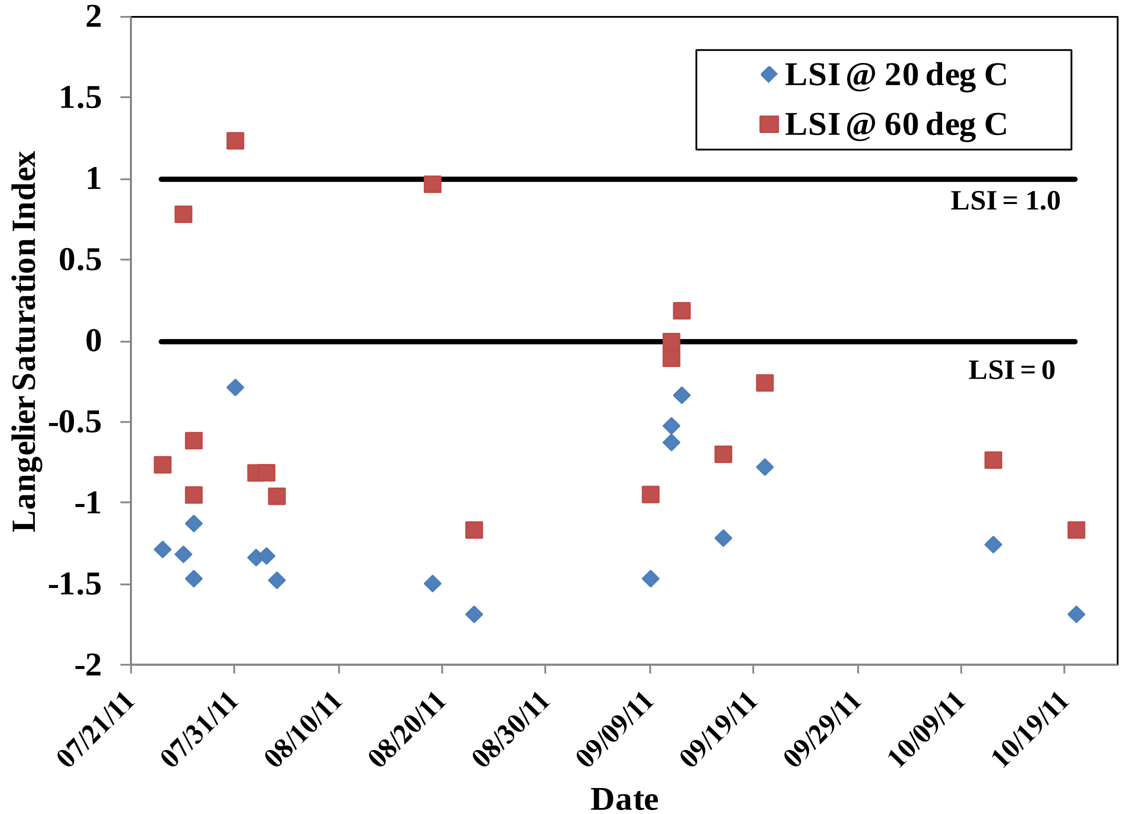

Figure 9. Langelier saturation index results of WBA IX treated water for test periods 1-4.

As discussed previously in Section 3.2.3, this failure is attributed to the operational difficulties experienced with the package soda ash system that was integrated into the WBA system to provide posttreatment capabilities. The soda ash system experienced large amounts of scaling in the dissolver tank, which often plugged the y-strainers on the suction side of the soda ash dosing pumps. This plugging prevented the required amount of dilute soda ash solution from being delivered to the inline static mixer injector. In addition, major scaling was observed throughout the equipment and piping associated with the soda ash system. This scaling was very problematic at the injector of the inline static mixer. When plugged with scale, the amounts of soda ash solution needed for raising pH and alkalinity of the treated water were not obtained.

5.6.3 Nitrosamine Analysis

Nitrosamine compounds have become an issue of concern to California regulators for ion exchange treatment systems. As a requirement for permitting this demonstration, CDPH recommended that nitrosamine sampling be performed at specific intervals. Groundwater and treated groundwater samples were obtained at < 5 BVs from the start of the first test period; treated water sample at the conclusion of the first test period (before regeneration); and a treated water sample < 5 BVs after the regenerated vessel (Vessel A) was returned to service. All samples were analyzed by Weck Laboratories using USEPA Method 521. Analytes included NDEA, NDMA, NDBA, NDPA, NMEA, NMOR, NPIP, and NPYR. The reportable limit for each of these analytes is 2 ng/L. NDEA and NPIP were observed at concentrations above the

reportable limit at < 5 BVs after startup, but were non-detect throughout the remainder of the demonstration. According to Purolite, low-level nitrosamine formation can occur if resin is stored for extended periods of time prior to use. The WBA resin was loaded into the IX vessels several months prior to demonstration testing. Once placed into service, the nitrosamine concentration was quickly reduced to non-detectable levels. Results are shown in Table 7.

Table 7. Certified Laboratory Results of Nitrosamines.

USEPA Method 521 Nitrosamines (ng/L)	Sample Points			
	GW 07/18 @ 1029	**FTGW 07/18 @ 1029**	**FTGW 07/24 @ 0810**	**Vessel A Rtn to Svc (<5 BV) 07/27 @1117**
N-Nitrosodiethylamine (NDEA)	ND	26	ND	ND
N-Nitrosodimethylamine (NDMA)	ND	ND	ND	ND
N-Nitrosodi-n-butylamine (NDBA)	ND	ND	ND	ND
N-Nitrosodi-n-propylamine (NDPA)	ND	ND	ND	ND
N-Nitrosomethylethylamine (NMEA)	ND	ND	ND	ND
N-Nitrosomorpholine (NMOR)	ND	ND	ND	ND
N-Nitrosopiperidine (NPIP)	ND	660	ND	ND
N-Nitrosopyrrolidine (NPYR)	ND	ND	ND	ND

ND = Non-detectable

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6.0 PERFORMANCE ASSESSMENT

The objective of this demonstration was to test and validate weak base ion exchange (WBA IX) technology using established performance objectives in order to obtain permitting and certification from the CDPH as an approved perchlorate treatment technology. Elevated groundwater perchlorate concentrations at Rialto No. 3 cause the site to be considered as an extremely impaired source as defined by the CDPH 97-005 Policy Memorandum. Based on previous pilot demonstrations, it was anticipated that O&M costs would be < $150/acre-foot.

Performance of the WBA system was evaluated by collecting and analyzing samples for perchlorate during ion exchange, regeneration, and treatment of residuals. Analytical results were used to assess and predict treatment performance of the WBA resin at the conditions tested. Operational data including flow rate, system pressure, pH, and consumption of chemicals were recorded and analyzed to validate operating performance and predict O&M costs.

6.1 PERFORMANCE OBJECTIVE: MEET PERCHLORATE REGULATORY STANDARD

6.1.1 Results

This performance objective was considered successful throughout the demonstration. The data requirements, success criteria, and a brief description of the results for this performance objective were discussed earlier in Sections 3.1.1-3.1.3, and 5.7.1. All WBA IX treated water samples analyzed by both ARA and Weck Laboratories during this demonstration were less than the DLR of 4 ppb.

6.2 PERFORMANCE OBJECTIVE: DEMONSTRATE POSTTREATMENT CAPABILITIES

6.2.1 Results

The performance objective for posttreatment was to control and adjust pH and alkalinity of the fully treated water to acceptable levels (0 < LSI < 1.0) with regard to corrosiveness or scaling tendencies prior to distribution. As discussed previously in Sections 3.2.3. and 5.7.2., this performance objective was not met. While this may appear to be a failure of the objective, the problems responsible are mechanical in nature and are easily remedied. Scaling issues were frequently observed in the soda ash mix tank, suction strainers, and the injector of the soda ash static mixer, preventing the required amount of soda ash to be dosed into the treated water. This scaling can be eliminated (or minimized) by installing media canisters to soften the recycled treated water prior to dilution of the soda ash in the dissolver tank of the package soda ash system. Also, the soda ash static mixer was sized specifically for the WBA system, but did not effectively mix the dilute soda ash. Mixing the soda ash with treated water would improve greatly by implementing a two-stage mixing process identical to that used to pre-dilute and mix sulfuric acid in the pretreatment step of the system. Additionally, the static mixer must be placed further upstream from the pH probes to allow more reaction time prior to pH measurement and sampling for LSI.

6.3 PERFORMANCE OBJECTIVE: MINIMIZE PROCESS WASTE

6.3.1 Results

One of the key benefits of the WBA process is the minimization of process waste created during the resin regeneration process. Process waste is defined as the "spent" regenerating solution that is generated by the regeneration process, scavenged, and pumped into the 10,500 gallon waste storage tank onsite (TK-701). A table of the key wastewater characteristics of this spent regenerating solution is shown below in Table 8. These characteristics were analyzed as a requirement for obtaining a disposal permit through the city of San Bernardino Municipal Water Department Water Reclamation Plant for use of the Inland Empire Brine Line (IEBL) Santa Ana Watershed Project Authority.

Table 8. Regeneration waste properties.

Analysis	Units	Results
USEPA 625–Semivolatile Organic Compounds	µg/L	All were ND
pH		11.8
BOD	mg/L	23
TSS	mg/L	280
TDS	mg/L	63,000
VSS	mg/L	14
Dissolved Organic Carbon	mg/L	21
Hardness as $CaCO_3$, Total	mg/L	140
USEPA 200.7–Metals		
Arsenic, Total	mg/L	0.024
Cadmium, Total	mg/L	ND
Calcium, Total	mg/L	52
Chromium, Total	mg/L	0.079
Copper, Total	mg/L	ND
Lead, Total	mg/L	ND
Magnesium, Total	mg/L	1.7
Nickel, Total	mg/L	ND
Silica as SiO2, Total	mg/L	21
Silver, Total	mg/L	ND
Zinc, Total	mg/L	ND
USEPA 245.1–Mercury, Total	mg/L	ND
USEPA 314.0–Perchlorate	µg/L	ND
USEPA 324–Volatile Organics	µg/L	All were ND
USEPA 608–Chlorinated Pesticides and/or PCBs	µg/L	All were ND
Oil & Grease	mg/L	ND
Sulfide, soluble	mg/L	ND
Sulfide, Total	mg/L	ND
Cyanide, Free (amenable)	mg/L	ND
Cyanide, Total	mg/L	ND
USEPA 300.0–Anions		
Chloride	mg/L	1500
Nitrate	mg/L	610
Sulfate	mg/L	28,000

PCB = polychlorinated biphenyl

The amount of waste disposed during this demonstration of was calculated as a percentage of the total groundwater treated during each test period. The percentage of waste created was determined to be 0.07% of the total water treated during Test Periods 1-3. Note that because the typical online regeneration procedure could not be followed after Test Period 4, the data was not included in this determination. Data used to calculate this number is shown below in Table 9.

Table 9. Percent waste generated by the WBA IX.

Disposal Date	Test Period	Vessel Regenerated	Water Treated (G)	Regen Waste Disposed (G)	% Regen Waste
9-Sep	1	A	3,505,780	5000	0.14%
	2	B	5,919,575	4800	0.08%
13-Sep	3	A	10,685,200	5000	0.05%
		TOTALS	20,110,555	14,800	**0.07%**

It must also be noted that during each test period, the resin was not loaded to capacity. The first two regenerations were conducted to minimize virgin resin effects and the third was conducted based on time limitations and budget constraints. Once the resin is permitted to treat closer to the 9000 BV breakthrough capacity, the percentage regeneration waste will be much lower.

6.4 PERFORMANCE OBJECTIVE: TREATMENT OF SPENT REGENERATING STREAM

6.4.1 Results

The performance criterion for treating the spent regenerant was to remove perchlorate from the spent regenerant solutions to concentrations less than 100 ppb. As described earlier, perchlorate was removed from the spent regeneration waste prior to disposal using a scavenger resin approach. This process consisted of passing the spent regenerant through two ion exchange vessels that were configured in series. Each vessel contained approximately 52.5 ft^3 of Purolite A530E SBA resin, which is highly selective for perchlorate. Perchlorate was removed as the spent regenerating solution passed through the scavenger resin for storage in wastewater holding tank TK-701 (10,500 gallons). ARA laboratory results using USEPA 314.0 show that the spent regenerant was successfully treated to levels below the detection limit (< 1.4 ppb). A summary of anion and TDS concentrations of both the spent regenerant and the treated regenerant for disposal are shown below in Table 10.

Table 10. Anion and TDS concentrations in spent regenerant before and after scavenging with Purolite A530E SBA.

Date	Test Period	Regen Solution	USEPA 314.0 Perchlorate (µg/L)	Anions (mg/L)			TDS (mg/L)
				Cl^-	NO_3^-	SO_4	
07/25/11	1	Spent	7,737	170	3951	17,000	40,000
		Treated	ND	605	108	18,000	35,000
08/01/11	2	Spent	16,648	274	5699	20,000	61,000
		Treated	ND	1205	534	24,000	58,000
09/10/11	3	Spent	35,951	334	6555	22,000	80,000
		Treated	ND	680	5051	24,000	82,000

6.5 PERFORMANCE OBJECTIVE: PERCHLORATE BLEED FROM REGENERATED VESSEL

6.5.1 Results

During the WBA IX regeneration process, a rinse step at the conclusion of resin regeneration was used to reduce and/or eliminate perchlorate bleed. To determine the effectiveness of the rinsing process, perchlorate data from samples analyzed by both ARA and the certified laboratory were evaluated to determine whether any perchlorate bleed was observed after the newly regenerated vessels were placed back online. Samples were obtained for this determination to bracket data from < 300 BV's of the vessel being placed back online until the next available sample point (<= 2500 BV's). All data shows that perchlorate bleed was below the performance objective of 4 ppb. Samples analyzed for perchlorate by ARA were below the detection limit (1.4 ppb) and are shown in Table 11. Similar samples analyzed by Weck Laboratories mirror ARA analyses (Table 12).

Table 11. ARA laboratory results of regenerated vessel bleed.

Test Period	Date of Regeneration	Regenerated Vessel	Treated Water Sample Date	Approximate BVs Treated	Perchlorate Conc. (ppb)
1	07/25-07/27	A	7/27/2011	19	ND
			7/28/2011	326	ND
2	08/01-08/02	B	8/3/2011	291	ND
			8/4/2011	460	ND
3	09/10-09/11	A	9/12/2011	225	ND
			9/13/2011	533	ND

Table 12. Certified laboratory results of regenerated vessel bleed.

Test Period	Date of Regeneration	Regenerated Vessel	Treated Water Sample Date	Approximate BVs Treated	Perchlorate Conc. (ppb)
1	07/25-07/27	A	07/27/11	10	ND
			07/31/11	2260	0.22
2	08/01-08/02	B	08/03/11	300	ND
			08/05/11	1280	0.15
3	09/10-09/11	A	09/12/11	200	0.14
			09/14/11	1490	0.27

6.6 PERFORMANCE OBJECTIVE: TREATMENT FLOW RATE

6.6.1 Results

During this demonstration, the WBA IX system did not quite reach the treatment flow rate of 2.5 gpm/ft^3 (875 gpm). The average flow throughout the demonstration was 2.29 gpm/ft^3 (800 gpm). This was due to a large pressure drop observed across the Liqui-Cell membranes used in the pretreatment system. As flow rates increased above 800 gpm, pressures at the pump would rise above the high pressure safety interlock (90 psig), causing the system to shut down. This problem may be rectified by performing periodic cleaning of the membranes. According to

Membrana (manufacturer of the membranes), any substantial biological growth or other particulates from the groundwater accumulating on the surface of the membranes will cause increased pressure drop across the membranes. Another solution would be adding another membrane pair to the existing manifold of three membrane pairs, which would allow the flow to be further spread across additional membrane surface area, lowering the pressure drop. These two changes would solve this issue.

6.7 PERFORMANCE OBJECTIVE: OPERATING COSTS

6.7.1 Results

Operating costs are critical in determining if the WBA process is competitive compared to existing perchlorate treatment systems. Activities and materials that contribute to O&M costs were documented and reported in dollars per acre-foot of water treated. Operating costs were calculated based on actual consumption rates and costs that were observed during the demonstration. This performance objective will be discussed in detail in Section 7.0, Cost Assessment.

6.8 PERFORMANCE OBJECTIVE: SYSTEM SCALABILITY

6.8.1 Results

During this demonstration, system scalability was successfully met. Although the first regeneration required approximately 72 hours due to mechanical and programming issues, the second and third were achieved in less than 48 hours. Due to operational problems, getting a consistent source of ground water for the WBA IX from Rialto No. 3 was difficult. The demonstration was discontinued before a resin treatment capacity could be established. Instead, the capacity of the resin was calculated using a more recent model for the D4170 WBA resin constructed using previous demonstration data (ESTCP ER-0312). Based on the current WBA IX flow rate capacity (800 gpm, or 2.29 gpm/ft^3) and Rialto No. 3 groundwater characteristics, the model supports the earlier estimates from the Fontana, CA pilot demonstration that the lead vessel will treat 9000 BVs before regeneration is required. This provides 21 days of operation before regeneration of the lead vessel is required. Based on that number, the existing onsite equipment will easily support the two additional ion exchange treatment trains. Regeneration events could be staggered to provide adequate time for regeneration. Additionally, if changes are made to the system to enable operation at the design flow rate of 1000 gpm (2.86 gpm/ft^3) at the above predicted capacities, regeneration of the lead vessel of each train will be required every 16 days, which would still allow for the addition of two more ion exchange trains.

6.9 PERFORMANCE OBJECTIVE: PREDICT WBA RESIN CAPACITY

6.9.1 Results

During this demonstration, breakthrough capacity of the resin in the lead vessel was not observed. During the fourth test period, non-continuous supplies of water from Rialto No. 3 well and program constraints resulted in termination of the demonstration before breakthrough was reached. Sampling indicated that the resin was approaching breakthrough concentrations, or 8-9 ppb (50% of the groundwater feed perchlorate concentration). Three of the final samples

indicated that the perchlorate was leveling off at six ppb at 6900 BVs, but then the system experienced a three week shutdown due to a combination of problems with the Rialto No. 3 well site and problems with the soda ash system and static mixer/injector that required maintenance and repairs to be effected. When the system was repaired and restarted, sampling indicated that perchlorate concentration had dropped to 2.9 ppb at 7300 BVs. This is shown below in Figure 10. Only two days of part time operation were accomplished before the Rialto No. well experienced more operational problems and program constraints halted the demonstration.

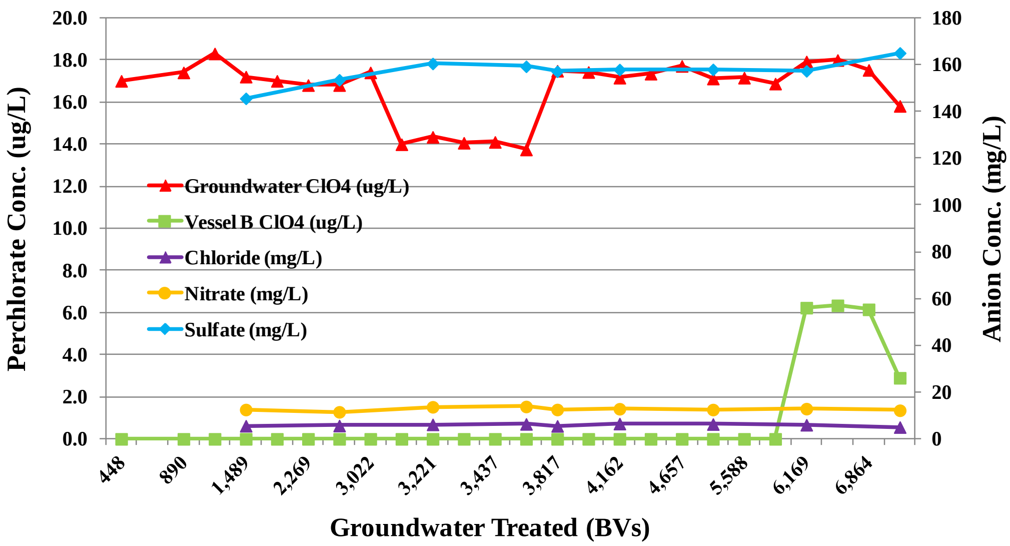

Figure 10. Test period 4: Lead Vessel B perchlorate and anion concentrations.

Because pilot operation was terminated before perchlorate breakthrough was observed, it should be noted that the actual capacity of the resin is greater than demonstrated. During the Phase 2 field demonstration at Redstone Arsenal in 2005 (ESTCP Project CU-0312), the WBA resin reached a capacity of 6500 BVs at a treatment rate that varied from 2.25-3.00 gpm/ft^3 with much higher groundwater perchlorate concentrations (2200 ppb). In addition, during the Phase 3 field drinking water treatment demonstration at Fontana in 2006 (ESTCP Project ER-0312), a higher treatment capacity of 9,700 BVs at a rate of > 3.0 gpm/ft^3 was observed, although at a lower perchlorate influent concentration (8.0 ppb). Although the breakthrough capacity was not able to be demonstrated, the current capacity can be calculated using a model for the D4170 WBA resin constructed from those demonstrations. Using the Rialto treatment rate of 800 gpm (2.29 gpm/ft^3) and the Rialto No. 3 groundwater characteristics, this model supports the earlier estimates that the lead vessel will treat 9000 BVs before regeneration is required.

6.10 PERFORMANCE OBJECTIVE: SYSTEM CONTROL DURING TREATMENT AND REGENERATION CYCLES

6.10.1 Results

During normal operations, the performance objective was met. The use of the touch screen by a single operator for monitoring and controlling/adjusting system control parameters was very straightforward. Completing checklists, sampling, and downloading data from the DAQ system also was handled by a single operator. During regeneration or mechanical troubleshooting, it is recommended that two or more operators be on site. Because the system is operated from the PLC touch screen in the control room, it is difficult for a single operator to observe what the system is actually doing during trouble shooting or regeneration.

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7.0 COST ASSESSMENT

7.1 COST MODEL

The purpose of this demonstration was not only to demonstrate the WBA IX technology, but also to validate equipment, construction, and O&M costs of the WBA IX process. To accomplish this, data for various cost elements of the WBA process were identified and collected, as presented below in Table 13. Data for each element was collected for the duration of the demonstration effort. Detailed descriptions of each cost element are provided in subsequent sections. This data was compared and integrated into previously derived WBA process cost models in order to establish a robust, realistic cost model for implementing the WBA IX technology. When modeling the implementation and operating costs of the WBA technology, care should be taken to apply the appropriate site specific elements to the model. For example, different methods may be employed to remove excess CO_2 generated during pretreatment of the influent water such as membranes, air stripping, or no treatment. The method selected will impact the equipment, electrical, and consumable costs.

Table 13. Cost Model Elements for the WBA IX Process.

Cost Element	Tracked Data	Units
Design, Construction, and Installation	Design Engineering, Construction Management, Equipment and Installation. Costs include actual equipment costs, construction management, and installation costs.	$/1000 gpm treatment system
Consumable Materials	Consumables tracked and documented include: • Sulfuric acid • Sodium hydroxide • Sodium carbonate (soda ash) • Strong base anion resin for scavenging • Weak base anion resin for primary treatment • Gas separation membranes • Miscellaneous chemicals and supplies	$/acre-foot water treated
Waste Disposal	Disposal of treated spent regenerating solution (transport and disposal fee).	$/acre-foot water treated
	Untracked Elements	
Electricity	Total electrical consumption of the demonstration system was calculated based upon installed equipment, usage rates, and load factors.	$/acre-foot water treated
Labor	Labor required for operating and maintaining system.	$/acre-foot water treated

7.1.1 Cost Element: Construction and Installation

Equipment, construction management, and installation cost data were tracked from actual costs of the subcontract with Carollo Engineers for design and construction of the 1000 gpm demonstration unit. Equipment costs were based on invoices from the Carollo subcontract and on invoices for equipment purchased by ARA. Total equipment purchases for the 1000 gpm system totaled $1.958M, with system installation costs totaling $466K. To derive cost estimates for different sized systems, standard industry practice scaling factors may be used to derive cost estimates using the six-tenths power factor rule. According to this rule, if the cost of a given unit

at one capacity is known, the cost of a similar unit with X times the capacity of the first is X 0.6 times the cost of the initial unit.

In addition, design, engineering, and management costs are much greater for a first-of-a-kind technology demonstration than for the construction and installation of additional similar systems. There are also unique costs for the management and reporting requirements of an ESTCP demonstration. For input into the cost model, design and engineering costs can be estimated based upon a factor of the actual delivered equipment costs. This factor is usually some percentage of the equipment costs.

7.1.2 Cost Element: Consumable Materials

7.1.2.1 Sulfuric Acid

Sulfuric acid (98 wt%) was used to lower the pH of the ground water during pretreatment and at the end of the regeneration process to restore the resin to the active ionized or protonated form. The size of the storage tank permitted procurement of sulfuric acid in full tank truck quantities. At the time of the 1000 gpm system demonstration, market pricing of sulfuric acid for the California site was at an all-time high of $0.215/lb. A five year U.S. average price, which is more reflective of the current market pricing of sulfuric acid, is approximately $0.12/lb for bulk chemical purchases. The acid storage tank level was monitored and recorded by the data acquisition system so that acid consumption could be calculated for any time period during the demonstration. During steady-state operation (between regeneration events), the daily acid consumption and acid consumption per acre-foot of treated water were calculated.

Acid required for WBA resin protonation during the regeneration process was determined separately. Acid needed for each regeneration-protonation cycle was measured using a digital flowmeter/totalizer that was monitored by the data acquisition system. Acid consumption per acre-foot of water was calculated based on the number of acre-feet of water treated before regeneration was required.

7.1.2.2 Sodium Hydroxide

A 25 wt% NaOH caustic solution was used to regenerate the WBA resin. The size of the storage tank permitted procurement of 25% NaOH solution in full tank truck quantities. Current market pricing and market pricing of sodium hydroxide during the demonstration were $0.1675/lb for bulk chemical delivery. 50% NaOH is more economical, but 25% was selected to eliminate the potential for precipitation of solid NaOH during the winter months. The caustic storage tank level was monitored and recorded by the data acquisition system so that caustic consumption could be calculated for any time period during the demonstration. The volume of caustic required for each regeneration-protonation cycle was measured using a digital flowmeter/totalizer that was monitored by the data acquisition system. Caustic consumption per acre-foot of water was calculated based on the number of acre-feet of water treated before regeneration was required.

7.1.2.3 Soda Ash

Soda ash (Na_2CO_3) solution was used to restore the pH and alkalinity of the treated water to acceptable levels prior to discharge to the reservoir. Solid soda ash was used to prepare a 3% soda ash solution on site. For the demonstration, soda ash was purchased in 50 pound bags delivered as 2,100 pound pallets at $0.3225/lb. This is not the most economical approach. Soda ash also can be delivered in 1000-pound super-sacks, or by bulk, pneumatic truck. For this assessment, actual purchase price and consumption were used to determine soda ash costs.

The average soda ash consumption was calculated based on the number of 50-pound sacks consumed over an extended period of time (3-10 days). The consumption rate and cost per acre-foot of water treated were calculated from this usage rate.

7.1.2.4 Strong Base Anion Resin (Scavenger Resin)

The SBA resin scavenging system consists of two 60-ft^3 ion exchange vessels configured in series. Each vessel was charged with approximately 52.5-ft^3 of resin. There are three reasons for this design: 1) to prevent the inadvertent discharge of perchlorate-contaminated effluent; 2) achieve maximum loading of SBA resin in the lead vessel; and 3) to determine when perchlorate breakthrough of the lead vessel occurs. Based on previous pilot test data, breakthrough of the lead vessel was designed to occur during the demonstration. Treated water from the lead vessel was sampled and analyzed during each regeneration event in order to determine when breakthrough occurs. Breakthrough is defined as when perchlorate concentration of treated water from the lead vessel equals 20-50% of the perchlorate concentration of the spent regenerating solution being treated.

The cost of SBA resin change-out includes transportation costs, resin replacement costs ($240.95/$ft^3$), and spent resin disposal costs. The average cost per acre-foot of water treated was calculated based on the total amount of water treated up to perchlorate breakthrough and the total cost of resin replacement. Actual perchlorate loading on the SBA resin was determined. SBA resin cost is the only cost element that is dependent on the perchlorate concentration of the groundwater being treated. Based on demonstration test results, the cost of scavenger resin was determined as a function of perchlorate concentration in the groundwater.

7.1.2.5 Weak Base Anion Resin

The WBA resin is anticipated to provide acceptable performance for several years. However, since it will have a limited lifetime, and it is relatively expensive, the cost of the WBA resin must be factored into overall treatment costs. Resin cost was determined by the current market replacement cost of the WBA resin. Replacement cost includes transportation and disposal of the old resin. Resin life is estimated to be 10 years. The cost per acre-foot of water treated was calculated based on 700 cubic feet of resin (350 cubic feet per vessel) and the amount of water treated assuming system operation at the rated capacity (1000 gpm) for 360 days per year. The current market price of the WBA resin is $478.23/$ft^3$.

7.1.2.6 Gas Separation Membranes

Liquid-cell gas membranes are used to reduce dissolved CO_2 (carbonic acid) in the groundwater that is the result of the reaction between alkalinity in the water and the sulfuric acid used to maintain low pH in the WBA IX process. The WBA IX system can be operated without actively removing CO_2, but this would result in much higher consumption of soda ash necessary to restore treated water pH and alkalinity to levels acceptable for distribution as drinking water. Treatment cost per acre-foot of water treated was calculated both ways—with and without degassing. Liquid-cell membranes have a limited life expectancy. The current replacement price of an individual membrane is $10,140/each. The cost per acre-foot of water treated was calculated based on operation at the rated capacity (1000 gpm) for 360 days per year, and the replacement cost and life expectancy of the liquid-cell membranes. For input into the cost model, alternative, less expensive means of removing the CO_2 from groundwater may be considered (i.e., using a stripping tower prior to discharge of treated water to a reservoir). A stripping tower was not used for the Rialto demonstration due to the footprint and height restrictions at the site.

7.1.2.7 Miscellaneous Chemicals and Supplies

Other chemicals and supplies were consumed for routine maintenance and calibrations. These materials may include: bleach solution for disinfection components, pH buffers for calibrating pH probes, air filters for the membrane degasification system and air compressor, and oil for gearboxes. The approximate annual cost of miscellaneous chemicals and supplies was estimated to be $12,000 per year. The cost per acre-foot of water treated was calculated based on operation at the rated capacity (1000 gpm) for 360 days per year.

7.1.3 Cost Element: Electricity

Because operation of the WBA system was intermittent throughout the demonstration, power consumption was estimated/calculated based on equipment rating, frequency of operation, and a factored load rating. Total electrical cost per acre-foot was calculated using $0.10/kilowatt-hour based on the volume of water treated and estimated kilowatt-hours consumed during demonstration testing. For input into the cost model, site-specific requirements should be considered. For example, if booster pumps and membrane degassing are not required based upon site-specific requirements, then total power consumption per acre-foot would be drastically reduced.

7.1.4 Cost Element: Labor

Operating labor was estimated based on ARA personnel hours during normal, steady-state operation and regeneration. Labor hours per acre-foot of water treated were calculated based on operation at the rated capacity (1000 gpm) with 312 days of “normal” operation (1.5 labor hours per day) and 48 days of operation in “regeneration” mode (16 labor hours per regeneration). A labor rate of $75.00 per hour was used in all calculations. For use in the cost model, labor hours per acre-foot should be scaled accordingly. Doubling or halving the size of the system will not double or half the labor hours required for operation of the system and should be factored accordingly.

7.1.5 Cost Element: Waste Disposal

Ion exchange resin wastes are accounted for as part of WBA and SBA resin costs. The only additional waste produced during the demonstration was treated, spent regenerating solution. This solution contains no perchlorate. This waste was hauled by a local, commercial waste handler (K-Vac Environmental, Rancho Cucamonga, CA) to a local disposal facility/terminal in San Bernardino, CA. The pH requirement for disposal of this solution is 6.0-12.0. Adjustment of pH was sometimes required prior to pick up. The total cost of waste disposal included pH adjustment, pick-up and transportation, and the tipping fee at the terminal. Waste disposal cost per acre-foot of groundwater treated was calculated from the volume of wastewater produced per regeneration and the average regeneration frequency at the rated capacity (1000 gpm) for 360 days per year. Actual hauling costs to the San Bernardino facility were $800.00 per 10,000 gallons of spent regenerant, in addition to disposal fees of $0.054 per gallon.

7.2 COST DRIVERS

There are five main cost drivers for the WBA IX system: 1) perchlorate concentration of the feed water; 2) alkalinity of the feed water; 3) alkalinity of the treated water; 4) regeneration frequency; and 5) WBA resin costs. Each cost driver has site-specific or equipment-specific characteristics that impact costs that are discussed in the following sections. Soda ash consumption is dependent on sulfuric acid usage. If excess acid is used for pH reduction, higher amounts of soda ash will be required to neutralize pH during posttreatment.

7.2.1 Perchlorate Concentration

Overall, the cost advantage of WBA IX technology relative to conventional SBA technology is greater as perchlorate concentration in the groundwater increases. However, scavenger resin consumption is directly proportional to perchlorate concentration. Because perchlorate is very concentrated in the spent regenerating solutions, much more perchlorate can be exchanged onto a strong-base scavenger resin than is removed by the primary ion exchange resin (weak base or strong base, single-use resin) used to directly treat the groundwater. The perchlorate-loading capacity of the perchlorate-selective SBA resin milliequivalents (meq) per liter (meq/L) is directly proportional to the concentration of perchlorate in the spent regenerating solution. SBA resin used in single-use ion exchange systems to treat low perchlorate concentrations (10s of ppb) loads only a small fraction of the total available ion exchange sites with perchlorate. For instance, the highly selective Purolite A530E resin will load only ~30 meq of perchlorate from treating a typical groundwater source containing 20 ppb perchlorate, even though the total ion exchange capacity is greater than 600 meq. That is, only 5% capacity before breakthrough is observed and the resin must be removed and incinerated. However, because the spent regenerating solution from the WBA process has 2000-5000 times more perchlorate and lower ratios of competing anions, A530E resin will load over 90% (550 meq) of the exchangeable sites with perchlorate. This efficient use of SBA resin in the scavenging process reduces resin consumption by over 95% compared to single-use systems used for groundwater treatment.

In previous laboratory scavenger tests, Purolite A-530E resin was the most economical resin based on treatment capacity and replacement costs ($240.95 per cubic foot). SBA resin cost is the only cost driver/element that is dependent on the perchlorate concentration of the

groundwater being treated. The SBA resin cost as a function of groundwater perchlorate concentration is presented in Figure 11. The scavenger resin costs for this demo were determined to be $10.11 per acre-foot based on an average groundwater perchlorate concentration of 16 mg/L.

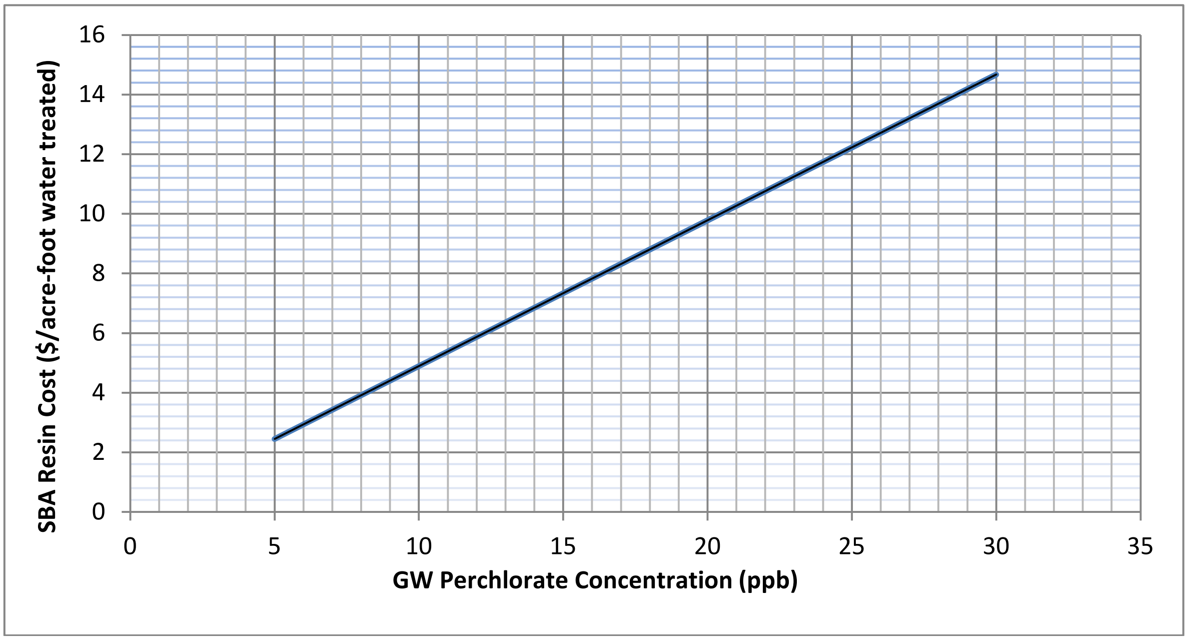

Figure 11. Scavenger SBA resin cost versus perchlorate concentration.

7.2.2 Groundwater Alkalinity

The amount of acid required for pretreatment to attain the pH necessary for good performance is directly proportional to groundwater alkalinity. Acid cost was determined to be $3.96/acre-foot for every 10 mg/L of total alkalinity in the groundwater, based on sulfuric acid pricing of $0.12 per pound, delivered. The pilot demonstration at Fontana, CA, resulted in an acid cost of $2.47/acre-foot for every 10 mg/L of alkalinity in the groundwater. This represents a 38% increase in acid use, which was caused by inadequate mixing of acid prior to pH measurement. This is a design issue that can be rectified by relocation of the pH probes to permit additional mixing time.

7.2.3 Treated Water Alkalinity

Posttreatment costs are directly proportional to the alkalinity required in the treated water to achieve a slightly negative LSI. The posttreatment approach is dependent on the water quality at each site. The approach taken during the Rialto demonstration was to lower the pH using sulfuric acid, remove excess dissolved CO_2 using Liqui-Cel membranes, and use sodium carbonate (soda ash) solution to return alkalinity to the desired level. Posttreatment cost (soda ash, electricity, membrane replacement) for this demonstration equated to $59/acre-foot based on an average of 54 ppm of residual alkalinity (as $CaCO_3$). Soda ash represents 80% of this cost and consumption was significantly higher than the theoretical requirement. This was due to the addition of excess acid during regeneration and pretreatment. Optimization of the regeneration, pretreatment, and posttreatment operations will significantly reduce both acid and soda ash consumption.

7.2.4 Resin Regeneration Frequency

Regeneration frequency and the related costs are dependent on resin treatment capacity, which is affected by competing anions present in a groundwater. For a given water composition, treatment capacity is relatively independent of perchlorate concentration below 100 ppb because the perchlorate isotherm is linear between 1 and 100 ppb. In other words, the quantity of the perchlorate anion that is exchanged is directly proportional to the concentration of perchlorate anion in untreated water.

7.2.5 WBA Resin Cost

Resin replacement cost is a major component of operating costs for several reasons. The commercial resin used in this demonstration (D4170) is produced by Purolite at $478.23 per cubic foot. While this resin is commercially produced, production rates are relatively low at this time. Higher production rates in the future may lead to reduced costs. Also, perchlorate treatment systems for drinking water require a "multi-barrier" or two-stage, lead-lag treatment configuration. This configuration, in effect, doubles the amount of resin necessary for a treatment process. The cost of resin replacement is $22.08 per acre-foot based on a 10-year service life.

7.3 COST ANALYSIS

The costs provided in Table 14 are normalized costs based on the current WBA IX configuration and the water quality at the Rialto 3 site. Observed costs were higher than projected due to problems identified and discussed in previous sections. Feed water pH ranged between 7.5 and 7.9 and the average alkalinity was 150 mg/L. Treated water pH was between 6.5 and 7.5 and the average alkalinity was 55 mg/L.

Table 14. Cost analysis for the WBA IX process.

Cost Element	Assumptions	Costs
Design, Construction, and Installation	1000 gpm system with multi-stage barrier treatment, boost pumps, membrane degasification, soda ash injection system for posttreatment.	$1.958M
Consumable Materials	Consumables include: • Sulfuric acid • Sodium hydroxide • Sodium carbonate (soda ash) • Strong base anion resin for scavenging • Weak base anion resin for primary treatment • Gas separation membranes • Miscellaneous chemicals and supplies	$42.79/AF $13.84/AF $38.19/AF $8.09/AF $22.08/AF $7.65/AF $7.54/AF
Waste disposal	Disposal of treated spent regenerating solution (transport and disposal fee).	$10.11/AF
	Untracked Elements	
Electricity	Total electrical consumption as configured for demo, including boost pumps and vacuum pumps for CO_2 degassing.	$20.44/AF
Labor	Labor required for operating and maintaining system.	$58.27/AF
	TOTAL:	**$229.00/AF**

7.3.1 Design/Construction/Installation

The design and management costs for a first-of-a-kind technology demonstration are much larger than would be expected for future implementations of this technology. When estimating design and engineering costs of future implementations of the WBA technology, a factor of the current delivered equipment costs, typically 30% (Peters, Timmerhaus, and West, 2002) should be used. Derived from 2008-2010 costs, Table 15 shows the total value of the subcontract with Carollo Engineering for design, construction, and installation of the Rialto 1000 gpm system ($1.958 million). Equipment costs for the demonstration unit totaled $1.492 million, with system installation costs totaling $466 thousand. The Rialto system capacity can be increased to 2000 gpm by installing an additional train of lead/lag vessels at minimal cost as the posttreatment system and regeneration system were designed for future expansion. In order to determine the price of systems larger than 2000 gpm, standard industry scaling factors such as the six-tenths power factor rule may be used (Peters, Timmerhaus, and West, 2002). According to this rule, if the cost of a given unit at one unit of capacity is known, the cost of a similar unit with X times the capacity of the first is X 0.6 times the cost of the initial unit.

Table 15. Equipment costs for the 1000 gpm WBA IX system.

Equipment	Cost ($)
Pretreatment:	
Feed Pumps (2 H 600 gpm)	$28,284
Membrana System (CO_2 degasification)	$80,375
Acid Storage Tank (6000 gal)	$29,254
Acid Feed Pump (5-10 gpm)	$4957
Heat Exchanger	$3847
Ion Exchange:	
Vessels, Packed Bed, Coated Stainless (2 H 9 foot diameter)	$292,003
Nozzles (1000, including gaskets)	$25,239
WBA Resin (Purolite D4170, 700 ft^3)	$287,000
Inert Material (Purolite IP-4, 82 ft^3)	$10,250
Posttreatment:	
Merrick Soda Ash Delivery System	$57,505
Regeneration:	
Scavenger Vessels (2 H 68 ft^3)	$24,660
SBA Resin (Purolite A530E, 105 ft^3)	$19,425
Acid Transfer Pump (10 gpm)	$4957
Caustic Transfer Pump (20 gpm)	$2904
Regeneration/Protonation Circulation Pump (500 gpm)	$10,053
Transfer Tank Pump (100 gpm)	$7489
IX Vessel Drain Pump (100 gpm)	$7489
Caustic Storage Tank (3000 gal)	$16,800
Regeneration Tank (4500 gal)	$18,781
Protonation Tank (1200 gal)	$7694
Transfer Tank (500 gal)	$1886
Control System/Electrical:	
Electrical Building	$22,628
VFD Panel	$17,619
Motor Starter Panel	$4991
PLC Control Panel	$30,084
Local Electrical Panel	$8318
Data Acquisition System	$5300
pH Controllers (10 units)	$10,578
Lighting	$8620
Air Compressor (20 cfm)	$5926
Subtotal Equipment	**$1,054,916**
Other Misc. Costs:	
Design, Piping, Static Mixers, Waste Storage Tank, Lighting, Wiring, pH Probes, Control Valves, Safety Equipment (eye wash, safety showers), Coatings, Chemical Containment Areas, Fencing, Additional Seismic Requirements	**$437,084**
Total Design/Equipment Costs	**$1,492,000**
Installation Costs	**$466,010**
Total Subcontract Value	**$1,958,010**

7.3.2 Cost Element: Consumable Materials

Observed and normalized consumable material costs are shown in Table 16. Observed costs are actual costs observed during the demonstration period. Because of the difficulty of determining costs due to problems experienced during the demonstration, normalized costs were developed based on the design treatment capacity of 9000 BVs (average alkalinity of 150 mg/L) at 1000 gpm over a 16 day operating cycle. In some cases material costs are based on bulk rates and/or average pricing, not including fuel costs and other miscellaneous charges. Each consumable item is discussed in detail in subsequent sections.

Table 16. Consumable material costs for operation of the WBA IX process.

Consumable Material	Actual Demonstration Cost, $/AF	Normalized Cost, $/AF
Sulfuric Acid, 98 wt %	$106.50	$42.79
Sodium Hydroxide, 25 wt%	$25.00	$13.84
Sodium Carbonate (Soda Ash)	$47.45	$38.19
Strong Base Anion Scavenger Resin, A530E [1]	--	$8.09
Weak Base Anion Resin, D4170 [1]	--	$22.08
Gas Separation Membranes [1]	--	$7.65
Misc. Chemicals & Supplies[2]	--	$7.54

[1] Actual costs were unable to be determined as these items' life cycle were longer than the demonstration
[2] This cost is based on a yearly budget of $12,000, which may vary from site to site

7.3.2.1 Sulfuric Acid

During this demonstration, acid consumption was 125 gallons per day (gpd), or 36 gallons/AF of treated water. Sulfuric acid market prices were higher than usual ($0.215/lb), which raised demonstration acid costs to $106.50/AF of treated water. Costs were based on actual volumes of water treated, actual flow rates, and recorded run times, which were considerably less due to the first two test periods being short cycles, and the third and fourth test periods being shortened due to intermittent operational difficulties experienced by the City of Rialto at the well site. This consumption rate is much higher (38%) than previous demonstrations due to mixing issues and non-steady state operation issues discussed in preceding sections. This sulfuric acid consumption rate is considered the maximum rate and must be adjusted based on groundwater alkalinity. Sulfuric acid cost can vary greatly; therefore, site-specific conditions should be used to model future implementations of this technology. Using the five year U.S. industry average of $0.12/lb, sulfuric acid costs drop to $42.79/AF of treated water. This is based on treating 9000 BV of groundwater with 150 ppm alkalinity at design flow rates of 1000 gpm over a 16 day cycle. Also, acid consumption drops to 103 gallons per day, or 23 gallons/AF of treated water.

7.3.2.2 Sodium Hydroxide

Actual caustic (25% NaOH) consumption over the demonstration period averaged 559 gallons per regeneration for each vessel (350 ft^3 of resin), or 35 gallons/AF treated water. Overall demonstration costs were $25.00/AF of treated water based on market costs of $0.1675/lb. However, each of the test periods (1-3) was shortened, either by design, or by time constraints caused by well site operational issues. Because of the shortened run times, the caustic

consumption rates were much higher. Using the same system operating conditions as with sulfuric acid (9000 BVs), a theoretical caustic consumption rate per regeneration was calculated based on the 1.4 equivalents per liter of resin plus a 5% excess, which equates to 481 gallons of 25% NaOH. This drops caustic consumption to 8 gallons/AF of treated water and $13.84/AF of treated water. Sodium hydroxide costs can vary greatly, therefore, site-specific conditions should be used to model future implementations of this technology.

7.3.2.3 Sodium Carbonate (Soda Ash)

Actual soda ash consumption during the demonstration averaged ~500 pounds per day (10 H 50 lb. bags). This equates to a soda ash consumption rate of 147.15 lbs/AF of treated water at an average cost of $47.45/AF of treated water. This consumption rate is considerably higher than predicted, but was greatly affected by excess acid used during pretreatment and regeneration. Normalizing costs as before drops treatment consumption rates to 118.42 lbs/AF of treated water and $38.19/AF of treated water. Soda ash consumption could be reduced proportionately and costs greatly lowered by optimization of chemical usage during the regeneration process, making improvements to the membrane pretreatment system, and making improvements to the soda ash delivery system.

7.3.2.4 Strong Base Anion Resin for Scavenging

Current market resin replacement costs, installation costs, transportation costs, and disposal costs were used to determine the scavenger resin costs. Calculations were based on the total amount of water treated to achieve perchlorate breakthrough in the lead scavenger vessel. Because the scavenger vessels were not operated to breakthrough during this demonstration, a theoretical cost was calculated. The lead and lag scavenger vessels each contained 52.5 ft^3 of Purolite A530E SBA resin (105 ft^3 total). The SBA resin consumption was projected to be 0.0336 ft^3 per acre-foot of water treated. At current market pricing of $240.95/ ft^3 resin, the average cost of the SBA resin was $8.09 per acre-foot of water treated. As discussed in Section 7.2.3, SBA resin cost is the only cost element that is dependent upon the perchlorate concentration of the groundwater being treated. Calculations were based on an average perchlorate concentration of 16 ppb during this demonstration at the Rialto No. 3 well site.

7.3.2.5 Weak Base Anion Resin for Primary Treatment

Cost calculations for the WBA resin were based on a resin life expectancy of 10 years, operating at the rated capacity of 1000 gpm for 360 days per year. As with scavenger resin costs, calculations take into consideration transportation costs, spent resin disposal, and resin installation using the current market cost for WBA resin. Each of the packed bed ion exchange vessels was loaded with 350 ft^3 WBA resin (700 ft^3 total). Based on current market pricing of $478.23/$ft^3$, the consumption rate is 0.046 ft^3 of resin per acre-foot, or $22.08 per acre-foot of water treated.

7.3.2.6 Gas Separation Membranes

The cost of the gas separation membranes is based on a life expectancy of five years and the system operating at the rated capacity of 1000 gpm for 360 days per year. With three pairs of

membranes (six membranes total) and a replacement cost of $10,140 each, the cost per acre-foot of water treated equates to $7.65.

7.3.2.7 Miscellaneous Chemicals and Supplies

The annual cost for miscellaneous chemicals and materials is estimated to be $12,000 per year. Based on the system operating at the rated capacity of 1000 gpm for 360 days per year, the average cost per acre-foot of water treated was determined to be $7.54. These costs are for supplies such as sump pumps, tools, electrical cords, disinfecting solutions, onsite pH analysis, etc.

7.3.3 Electricity

Electricity consumed during the demonstration was an untracked cost. Calculated power consumption was based on equipment ratings and duty cycles. The total amount of electricity consumed during the entire demonstration was approximately 24,548 kilowatt hours. Based on a rate of $0.10 per kW-hr and a total of 120.12 acre-foot of water treated during the demonstration, total electricity cost was $20.44 per acre-foot of water treated, or 204 kW-hr per acre-foot water treated. This number accounts for each of the three regenerations performed during the demonstration. Power consumption was dominated by the booster feed pumps (75% of total) and the liquid ring vacuum pump (19% of total). Depending on site-specific requirements, many applications may not require booster pumps or a liquid ring vacuum pump for membrane degassing as demonstrated in Rialto. Electrical costs representing the exclusion of various elements are calculated and shown in Table 17.

Table 17. WBA IX process electrical costs.

Electrical Elements	Total kW Required	Total kW-hr Used	Total Cost ($)	Cost ($) per acre-foot Water Treated
IX operations, as demonstrated	140	24548	$2,454.79	$20.44
IX operation, excl. regenerations	112	24289	$2,428.94	$20.22
IX operation, excl. booster & vacuum pumps	47	1600	$160.04	$1.33
IX operation, excl. regenerations, booster & vacuum pumps	19	1342	$134.19	$1.22

7.3.4 Labor

Labor hours were determined based on the normal operation and regeneration operation modes. From the demonstration, it was determined that under normal operating conditions, a single operator was needed on site for approximately 1.5 hours per day. During regeneration cycles, it was determined that two (2) operators would need to be on site intermittently for approximately eight hours per day. With the system operating at the rated capacity of 1000 gpm for 360 days per year at a $75.00/hr rate, labor costs were $58.27 per acre-foot of water treated. Labor costs per acre-foot of water treated may vary from site to site due to varying labor rates. Doubling or halving the size of the system will not double or half the labor hours required for operation of the system.

7.3.5 Waste Disposal

The only waste requiring disposal during the demonstration was the perchlorate-free, spent regenerating solution. Each regeneration cycle produced approximately 5000 gallons of the solution. A 10,500 gallon waste tank, located on site, allowed for two regenerations to be conducted before a certified waste hauler/environmental company would transport and dispose of this solution. The transportation costs for this process was $800 per 10,000 gallons of waste, with disposal fees of $0.054 per gallon. Assuming the system runs at capacity (1000 gpm) for 360 days per year, and 24 regenerations are performed throughout the year, the waste disposal costs would be $10.11 per acre-foot of water treated.

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8.0 IMPLEMENTATION ISSUES

8.1 ENVIRONMENTAL ISSUES AND IMPLEMENTATION

The City of Rialto has an existing permit for treating perchlorate using the single-use, SBA resin treatment process located at Rialto No. 3. In order to demonstrate the WBA system, ARA was required to go through a multi-step process to apply for an amendment to this permit. With the City's approval, an application for amending the permit, along with a Performance Objective Plan and an Operations Manual/Control Narrative, were submitted to CDPH. CDPH reviewed both documents and issued a permit amendment for the WBA system to be operated only as a pretreatment system to the existing treatment system. A treatment permit approving WBA technology as a primary treatment may be issued after review of the Final Report and completion of the permitting process. According to CDPH, implementation of this treatment technology at other sites will be approved on a case by case basis.

Additionally, the WBA system requires a permit for disposal of the waste produced during WBA resin regeneration. An application for a discharge permit was submitted to the San Bernardino Valley Municipal Water District (SBVMWD) in order to have a certified waste hauler dispose of this waste at the IEBL. Samples of the waste were analyzed by a certified laboratory for a list of pollutants and the results were submitted to SBVMWD. A site inspection was also conducted by an environmental technician from SBVMWD to create a process flow diagram for the permit. The permit was issued directly to ARA. If the City of Rialto chooses to operate the WBA system, they must re-apply for a permit that would be issued directly to the City.

8.2 END USER CONCERNS AND ISSUES

End users for this technology include DoD facilities, formally used defense sites, and municipal drinking water systems that have been contaminated with perchlorate by past DoD operations. In addition to drinking water applications, the technology can be used for pump-and-treat perchlorate remediation and to facilitate remediation of co-contaminants (such as VOCs) by removal of perchlorate to enable discharge or re-injection. The technology can also be applied to the treatment of other types of wastewater generated by munitions manufacturing or demilitarization operations.

Implementation of this technology is straightforward. Commercial, large-scale, ion exchange equipment for WBA resin technology is commonplace. The pretreatment section of the system consists of pH control unit operations with two-stage static mixing which is straight forward to design and engineer. Reducing the alkalinity/stripping of CO_2 from the groundwater feed can be accomplished using membrane treatment systems or stripping towers. Both methods are straightforward and are commercially available. The posttreatment system used to return alkalinity and raise the pH of the treated groundwater consists of a package soda ash delivery system combined with static mixers; both are commercially available. Treatment of residuals by an SBA resin scavenger ion exchange process is a proven technology.

The issues of primary concern for the end user concerning the WBA technology are: 1) operational complexity; 2) labor requirements; and 3) requirements for bulk chemicals onsite (i.e., acid, caustic, and soda ash).

8.2.1 Interfering Anions

The WBA resin has greater selectivity for perchlorate than other anions. However, the presence of competing anions such as chloride, nitrate, and/or sulfate will reduce the overall treatment capacity of the resin. WBA resin performance can be modeled based on site-specific groundwater characteristics.

8.2.2 Operational Complexity

The WBA IX system demonstrated at the Rialto No. 3 well site is an automated water treatment system. Automation of any technology brings a level of complexity to that technology. The PLC, operator interface (O/I), control software, and other associated electronics used to control the WBA system were off-the-shelf, and readily available. A computer engineer programmed the PLC system based on a predetermined control philosophy that allowed operators to control the system by means of input and monitoring screens at the O/I. In addition, the system could be operated in manual or automatic modes. Real-time data was also displayed on the monitoring screens. Operators must have a basic understanding of PLC systems, control logic, and the operating philosophy of the WBA system.

8.2.3 Labor Requirements

The WBA system, as designed in Rialto, CA, will require a single operator for approximately 1.5 hours per day. This operator can perform sampling, collect operational data, perform or monitor chemical re-supply, and basic maintenance. During the 48-hour regeneration cycles and major maintenance procedures, it is recommended that two operators be available onsite intermittently for eight hours per day. Once familiarity with the system has been established and operations streamlined, these requirements can be reduced.

8.2.4 Chemical Storage Requirements

Currently, bulk chemicals need to be stored onsite for the WBA system at the Rialto No. 3 site: sodium hydroxide (25%) in a 3000 gallon poly tank (T-501); sulfuric acid (93%) in a 6000 gallon poly tank (T-601); and four or five pallets (four or five H 2100 lb) of soda ash. The acid and caustic vessels are in sealed containment areas with sumps to protect against an accidental spill or release. Since soda ash is highly hygroscopic, it should be stored indoors or in a covered area to prevent moisture intrusion/hardening of the soda ash.

8.2.5 System Improvements

8.2.5.1 <u>Pretreatment</u>

In order to reduce the pressure drop experienced across the membranes and increase flow to the design capacity of 1000 gpm, the membrane system must be modified. An additional membrane pair must be installed to reduce the flow through each membrane train. In addition, the membrane system must be modified to allow for periodic cleaning to be performed.

Rotameters used to balance the airflow through the membranes were oversized for this application. Smaller rotameters will enable operators to better control airflow (and CO_2 removal) across the membranes.

Also, the membrane vendor (Membrana) recommended that the membranes and associated equipment be covered to provide protection from direct sunlight. If the WBA system is used as a permanent treatment system, this will prolong the life cycle of the membranes.

8.2.5.2 Posttreatment

The Merrick soda ash system was not designed for outdoor use. This system will require a cover to protect it from the elements. It is also recommended that softened water or RO water be used for dissolving solid soda ash in the dissolver tank of the Merrick soda ash system. If not, scale will form in the dissolver tank, soda ash feed pump strainers, piping, and in the injection quill of static mixer MX-401. Softening of the water will eliminate scale formation.

During this demonstration, LSI and pH of the treated water was difficult to control. To rectify this problem, two-stage mixing should be employed with the soda ash—identical to that employed in the pretreatment system with sulfuric acid. In this process, the soda ash would be premixed with a slip-stream of recycled treated water in a smaller static mixer, which would then be injected into the larger static mixer. To further assist mixing and increase residence time, the distance between the static mixer and the pH probes must be maximized.

8.3 PROCUREMENT ISSUES

This system is not considered a commercial off-the-shelf (COTS) system. Although the WBA system is composed of readily available commercial components, application of this technology to other sites will require additional engineering to meet site-specific requirements based on groundwater characteristics and onsite needs and/or restrictions.

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APPENDIX A

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